

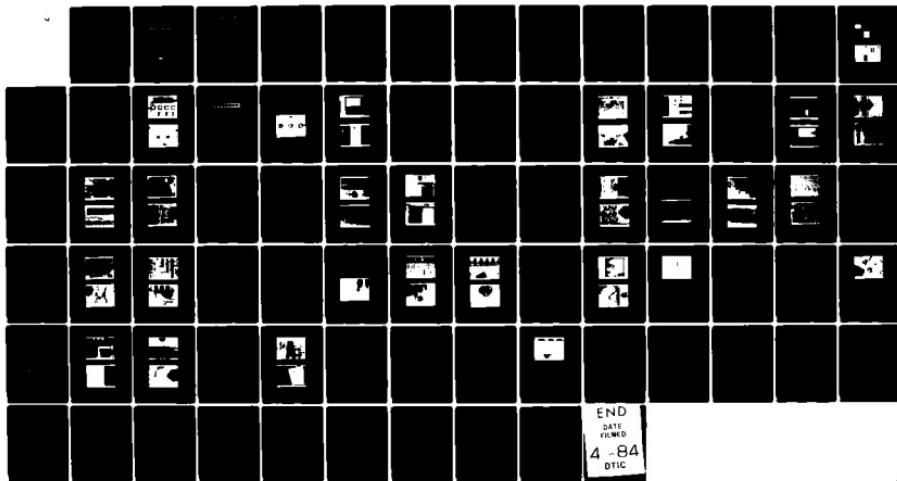
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AN EVALUATION OF PERMANENT SOLDER MASKS FOR HIGH
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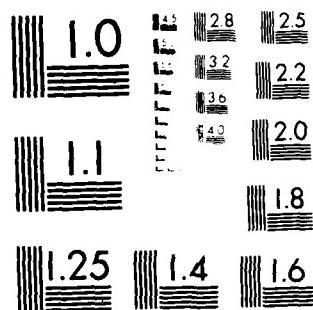
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An Evaluation of Permanent Solder Masks for High Reliability Applications

by

Donna J. Sanger
Engineering Department

FEBRUARY 1984

**NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555**



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FOREWORD (U)

The evaluation described in this report was completed in December 1983 and is a Naval Materials Command Manufacturing Technology project, program elements DNE 00215, 00218, and DNA 821006. Various permanent solder masks were examined in an effort to determine the acceptability of solder mask for use on military electronics.

This report has been reviewed for technical accuracy by Edwin B. Royce.

Approved by
D. J. RUSSELL, Head
Engineering Department
20 January 1984

Under authority of
K. A. DICKERSON
Capt., U. S. Navy
Commander

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(U) With more dense packaging of electronic subassembly printed wiring boards, it has become necessary for the military to fully understand materials and application problems of solder mask. This project was an attempt to experience and understand the problems associated with dry film and liquid permanent solder masks. Items such as registration, adherence, bubbles and voids, and environmental protection were examined. The result was a better understanding of each of these problems with conclusions that solder mask should be used only over bare copper circuitry and that liquid solder mask should not be used as an electrical insulating barrier.

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We wish to express appreciation to the solder mask manufacturers and the facilities that supported us by applying the masks. This organization does not qualify solder masks but is concerned with the process controls associated with the use of solder masks.

Jim D. Raby, *Head*
Electronics Manufacturing Support Office

INTRODUCTION

A solder mask is a polymeric coating that is applied to a printed circuit board in areas where solder wetting is not desired. There are permanent solder masks and removable solder masks this report deals with permanent solder masks which cannot be removed from the circuit board by ordinary solvents found in an electronics production area.

This study on the subject of solder mask was undertaken as a Navy Manufacturing Technology program to understand the benefits and problems associated with solder mask on a printed circuit board. Military contractors are expressing interest in using solder masks but, due to the many unknowns associated with the use of permanent solder masking, approval for use has been limited. This study was designed to determine the effects that a solder mask can have on high reliability military hardware.

Addressed in this effort are the cases of when it is appropriate to use a solder mask, the type of surface over which a mask can be applied without detrimental effects, and the application methods that will ensure the highest reliability of the hardware. Seven solder masks were evaluated in order to understand the difference between various brands and types of masks for each of these cases.

A solder mask is used to prevent bridging of closely spaced circuit traces during the wave soldering process. Wave soldering of circuits with spacing of 0.010 inch or less can be accomplished easily with the use of solder mask. Large ground planes can also be soldered easily with the use of solder mask but only if the mask is applied over a bare copper surface. Some solder masks have been designed to function as a protective insulating layer over circuitry to prevent electrical shorting of devices that are placed across the traces. Although not specifically designed for the purpose of environmental protection of the printed circuit board, solder mask does provide some protection from abrasion during storage, handling, and the assembly operation. Since solder masks are resistant to the common solvents used in the assembly operations, they provide protection to the circuit board in this way, also.

Solder mask on a printed circuit board can lead to many process problems if the user is not aware of the changes that a mask causes. The edge of the mask around the pads can trap flux and oil, leading to flaking and chipping of the mask; the smooth surface of some masks makes it difficult for conformal coating

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to adhere; uncured components in the mask can lead to processing problems later in the production cycle; misregistered mask can get on pads and in the plated-thru-holes causing solderability problems and deformation of fillets. A solder mask should have no detrimental effects on the hardware, e.g., flaking that produces chips of mask that can fall onto other circuit boards in an assembled unit. The mask should not affect the solderability of the circuit board. Some masks smear or bleed onto pad areas as a thin uncolored layer of resin that is not visible, but deters the solder wetting.

TESTING

A test plan was designed to determine the performance of various brands and types of solder masks over bare plated copper and over 60/40 plated tin lead. Seven different solder masks were investigated, including both the dry film and the screenable type masks. Boards were fabricated in-house in a prototype printed wiring board fabrication shop and then masked either commercially or by military contractors using a particular mask. For an accurate evaluation of the masks, it was best that they be applied according to the methods and practices of those who use the masks. The masking was not performed at the Naval Weapons Center because neither the necessary equipment nor the experience with the screening unique was available.

Masks were tested for mechanical, electrical, and environmental properties, including: adhesion, abrasion, surface resistivity, breakdown voltage, solvent resistance, flux resistance, moisture/temperature cycling, hydrolytic stability, solderability effects, and solder resistance. Masks were also visually checked for appearance, thickness, wrinkling, blistering, cracking, and lifting.

The following masks were tested: DuPont Vacerl 740FR, DuPont Vacerl 740S, Thiokol-Dynachem Laminar RM, Hysol SR1010, Hysol SR1000, Lonco 222-M, and MacDermid 9446. Both the DuPont and the Dynachem products are dry film solder masks that were applied by the vacuum lamination technique. The DuPont masks were processed with solvent, while the Dynachem product was processed aqueously. All three of these masks were cured using both a thermal cure and an ultraviolet cure. The other four masks were liquid masks that were manually screened, then thermally cured.

A test board approximately 4 x 3 inches was designed for this study. A circuit, a 1-inch² ground plane, a 0.035-inch "Y" pattern, an open area of laminate, and a 0.006-inch lines and spaces comb pattern with finger tabs along one edge for connection to the environmental test hookup were included in the test board. See Figure 1.

Boards were inspected, then masked according to the application parameters that are used in each particular company that performed the masking. All boards were masked in panel form, as four boards per panel. After completion of the cure, the boards were inspected at 20X for masking quality, including accuracy of registration, bleeding, loss of adhesion, inclusions, voids, pinholes, and areas of either thin deposit or extra heavy deposit of mask. Plated-thru-holes were also inspected for mask.

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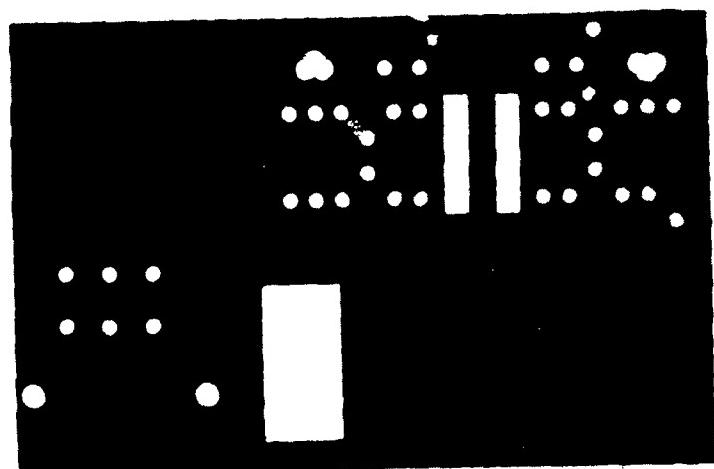
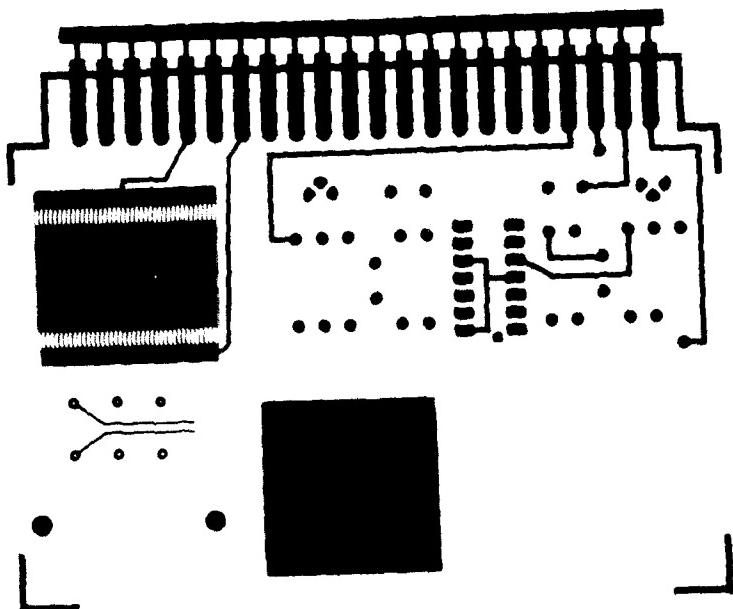


FIGURE 1. Test Board and Solder Mask Artwork.

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Following this inspection, the panels were cut into the separate boards. Machinability of the masks was noted during the trimming and sanding processes. Mechanical tests were performed for Taber abrasion, pencil abrasion, punch test, tape test, and cross-hatch adhesion on both the ground plane and the laminate areas. Small pieces of board were used for the solvent and flux resistance tests. The electrical tests surface resistivity and breakdown voltage were conducted on whole boards. An environmental test consisting of a moisture/temperature cycling according to MIL-STD-202 Method 106B was conducted. A hydrolytic stability test was performed on each mask according to IPC-TM 2.6.11. Later installation of an Electrovert hot air leveling system allowed evaluation of the masks for this process. Each test is described in the appendixes.

RESULTS

Results of the tests for each mask are discussed below.

DUPONT VACREL 740FR AND VACREL 740S

A visual inspection of Vacrel 740FR and Vacrel 740S dry film solder masks showed mask on the pads and in the plated-thru-holes. This was explained as a misalignment of the front-to-back registration in the solder mask artwork. Light scattering during the ultraviolet exposure period allowed the misaligned areas near the pad openings to be partially exposed. During the development process, the solvent was unable to remove the partially exposed mask, leaving rough and irregular edges on the holes. The rough edges easily chip and flake, settling onto other areas of the board, including the plated-thru-holes. See Figures 2 and 3.

The Vacrel 740 series masks are 0.004 inch thick before application. The thickness of the mask over the laminate and the traces was measured optically after microsectioning. An average thickness was taken from readings in three locations. See Figure 4. Both Vacrel 740FR and Vacrel 740S had thicknesses of 0.002 inch on the traces of the comb pattern and 0.004 inch on the laminate.

The Vacrel 740FR and the Vacrel 740S had similar properties in most of the tests performed. A 5H pencil hardness scratched the surface of both masks. Fifty cycles of Taber abrasion showed little wear; the mask over the conductor surfaces remained intact. The punch test, both before and after soldering, showed no damage over copper circuitry. The tin/lead areas were damaged both times.

The tape test for adhesion to laminate, tin lead, and copper circuitry caused no damage. The cross-hatch test showed little loss (5%) on the laminate and copper, but an unacceptable amount of loss (50%) on the tin lead. A cross-hatch test on copper after wave soldering again showed less than 5% loss.

The fluxes had no effect on either the Vacrel 740FR or the Vacrel 740S.

The solvents, except for methylene chloride, had no effect on either mask after 2 hours. The methylene chloride rapidly softened the Vacrel and within a 30-minute period, it could easily be removed from the laminate and tin lead.

The breakdown voltage for Vacrel 740FR was 3000 VAC before soldering and 2600 VAC after soldering and moisture/temperature cycling. The mask was not charred but there was a halo pattern on the mask where the electrode had been placed. The breakdown voltage for Vacrel 740S was 2450 VAC before soldering and 2500 VAC after soldering and moisture/temperature cycling.



FIGURE 2. Vactel 740FR. Solder Mask on Perimeter of Plated-Thru-Holes.

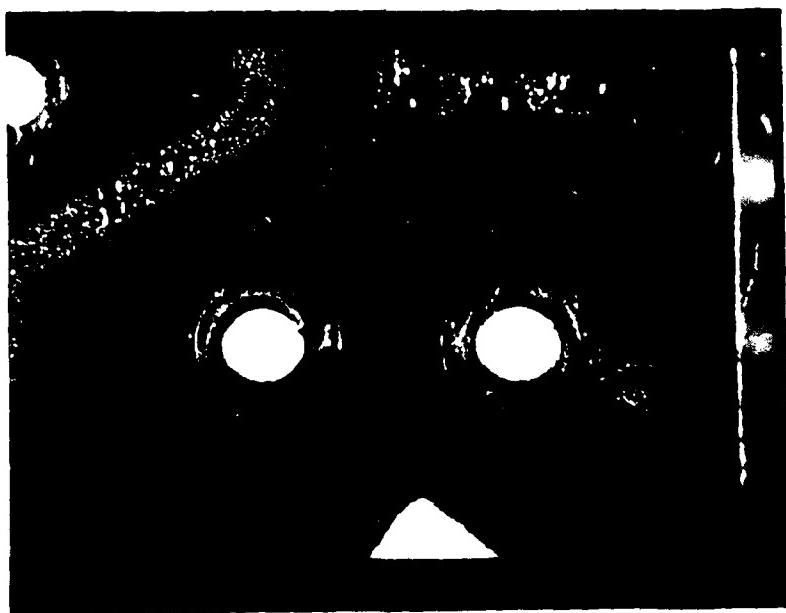


FIGURE 3. Vactel 740S. Solder Mask on Perimeter of Plated-Thru-Holes.

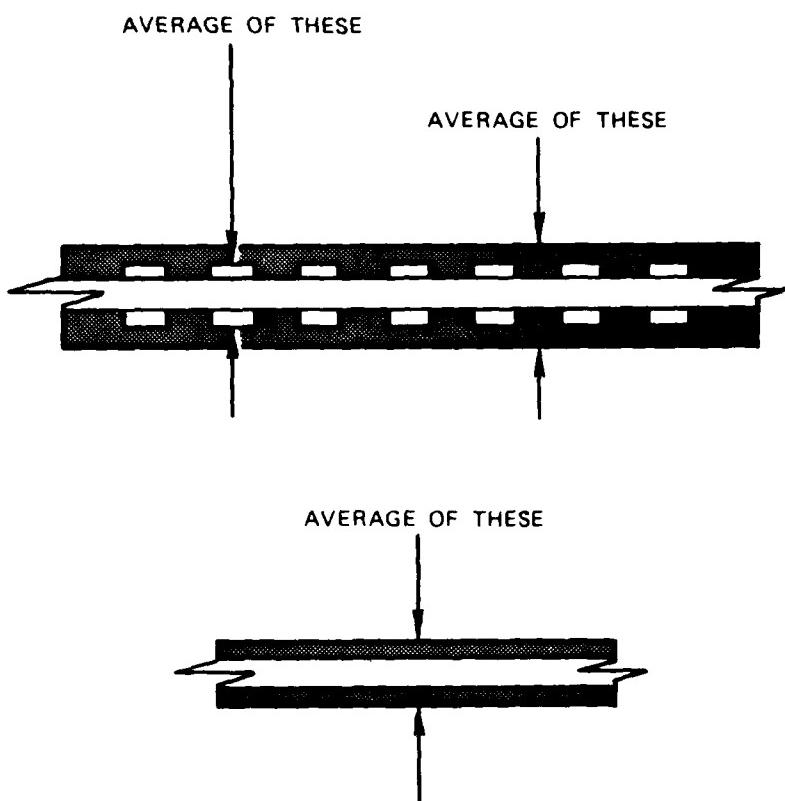


FIGURE 4. Solder Mask Thickness Measurement.

The surface resistivity was 3×10^{13} ohms/square for Vacerl 740FR both before and after soldering. Vacerl 740S was 2×10^{12} ohms/square.

The hydrolytic stability test caused no damage to the copper boards but the mask over the tin/lead samples became brittle and cracked.

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The net-soldering process using Vaezel 740FR solder mask on the boards soldering showed good acceptance of solder in the areas that did not have the flakes of partially exposed mask. When wave soldering the Vaezel 740FR coated boards pushed the mask up through the hole, leaving it loose on the surface of the fillet. See Figure 8. During wave soldering, the retinning action caused the mask to wrinkle entrapping flux to varying degrees. See Figure 6. The mask on the plane was very brittle, chipping off easily with normal handling procedures. See Figure 7. Wrinkling of the mask on the ground plane is unacceptable for military products because of the flux entrapment and the loose claps of mask that can be scattered across a board. In addition, it is impossible to properly conformally coat over an area that does not adhere to the board.

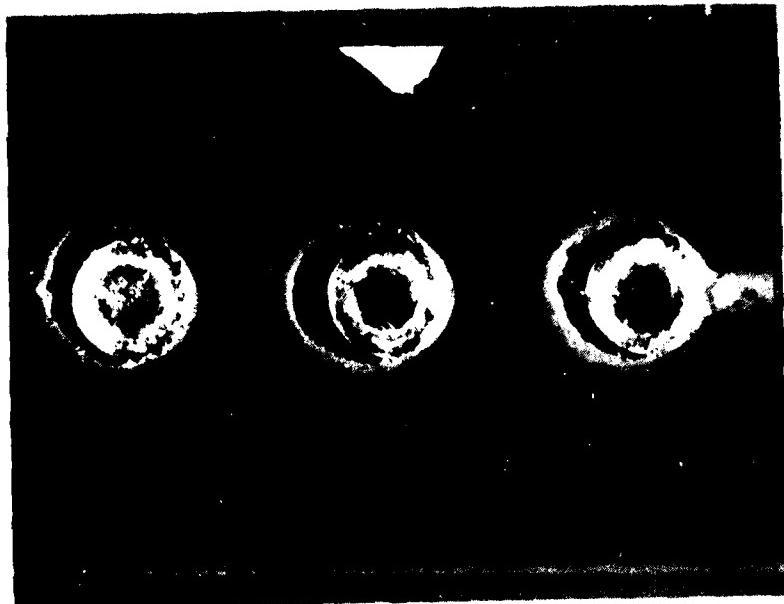


FIGURE 5. Vaezel 740FR, Solder Mask on the Fillets.

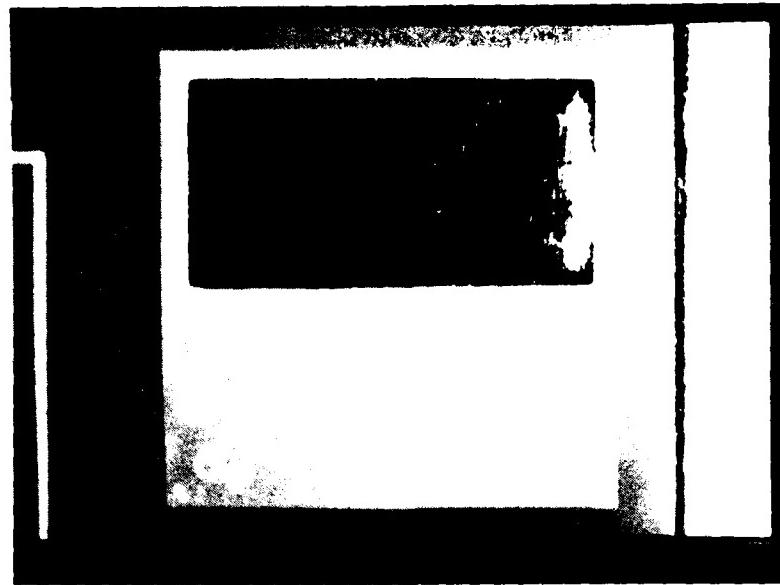


FIGURE 6. Vacrel 740FR, Wrinkled Mask and Trapped Flux on Ground Plane.

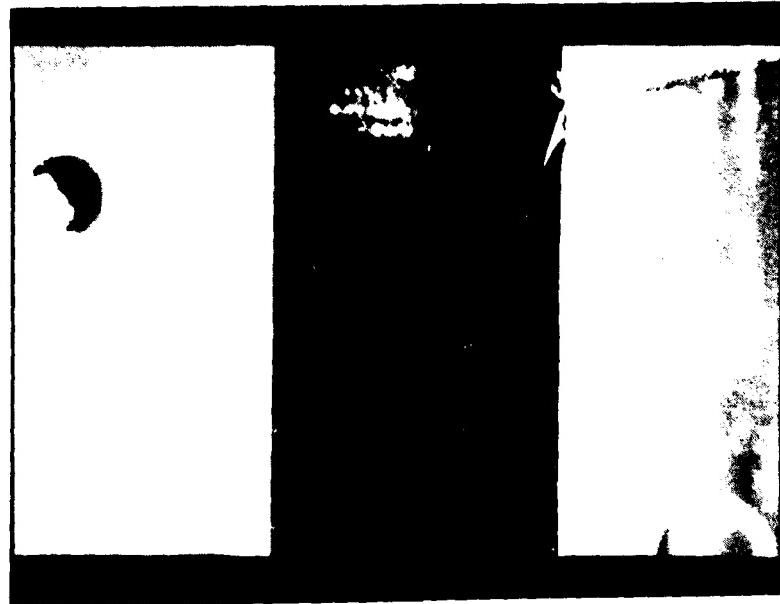


FIGURE 7. Vacrel 740FR, Flux Seeped From Under Chipped Mask on Ground Plane.

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A cleanliness test performed after wave soldering on three Vacrel 740FR boards showed an average of less than one microgram/square inch of ionic contamination a passing value for the cleanliness test.

The resistance measurements taken during the moisture/temperature cycling tests showed that Vacrel 740FR provided relatively good protection for the comb pattern. See Figures 8 and 9. Variations in board fabrication and processing could explain the samples that show resistance values lower than the standard unmasked board. The breaks in the pattern on the wave soldered side of the copper boards (bottom) are suspected to be operator error in reading the exponent of the resistance value.

The Vacrel 740FR boards were examined at 20X after the moisture/temperature cycling test. The mask in the corners of the ground plane had cracked on both the tin/lead and the copper boards. There was also some cracking on the edge of the comb patterns. Pockets of flux were still visible under the mask on the tin/lead ground plane.

Hot air leveling of the Vacrel 740FR copper boards caused no damage to the mask.

Due to a limited supply of boards masked with Vacrel 740S, evaluations were conducted on wave soldering and hot air leveling only. Wrinkling of the mask over the tin/lead occurred on the Vacrel 740S as it had on the Vacrel 740FR boards. Flux was trapped on the edges of the wrinkled areas. See Figure 10. The plated-thru-holes that had partially exposed mask on the edges did not accept solder. See Figure 11.

The hot air leveling process damaged the Vacrel 740S, causing bubbled areas on traces that chipped off when lightly touched. See Figures 12 and 13.

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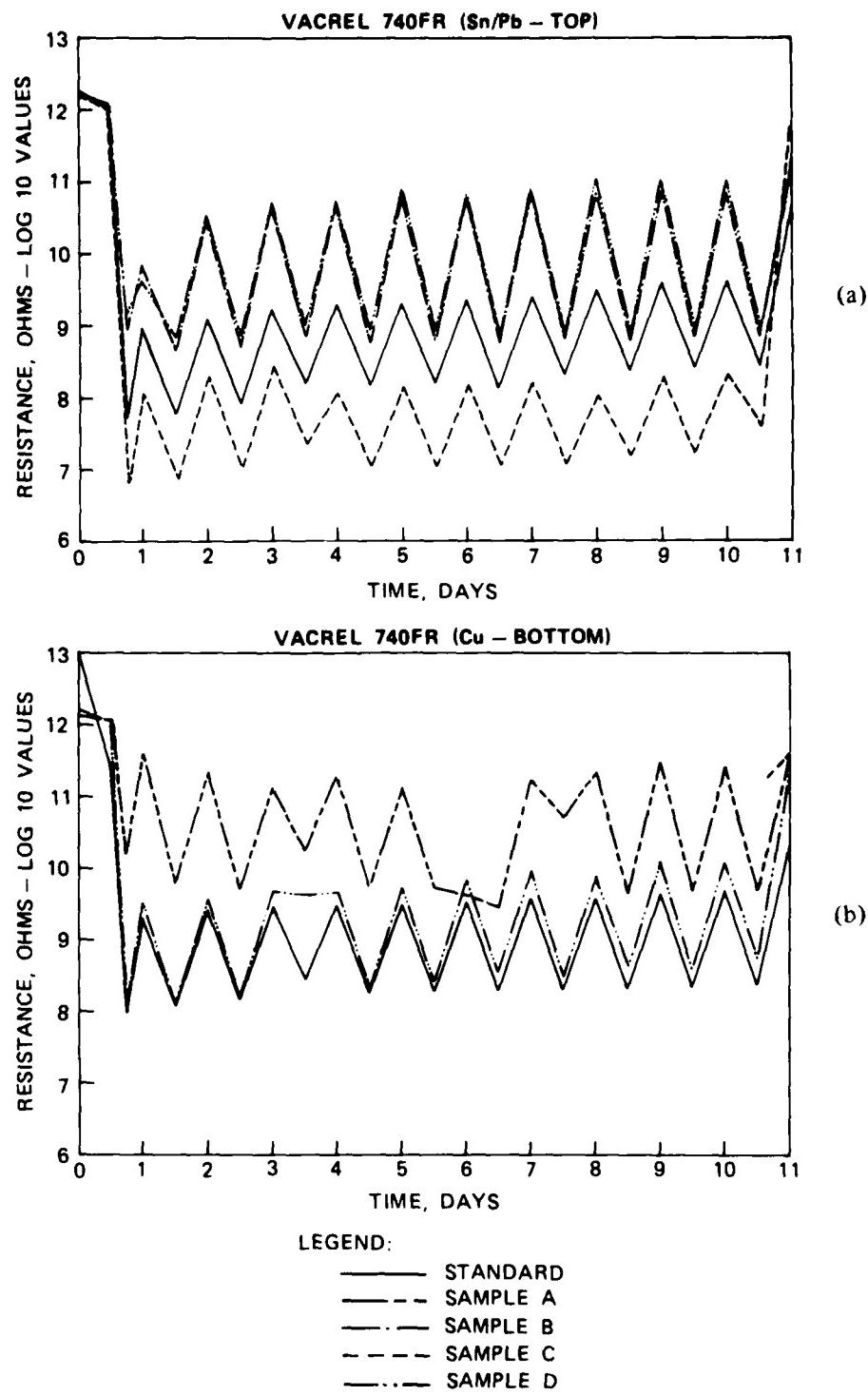


FIGURE 8. Vacrel 740FR, Resistance Values. (a) Tin/lead (top).
(b) copper (bottom).

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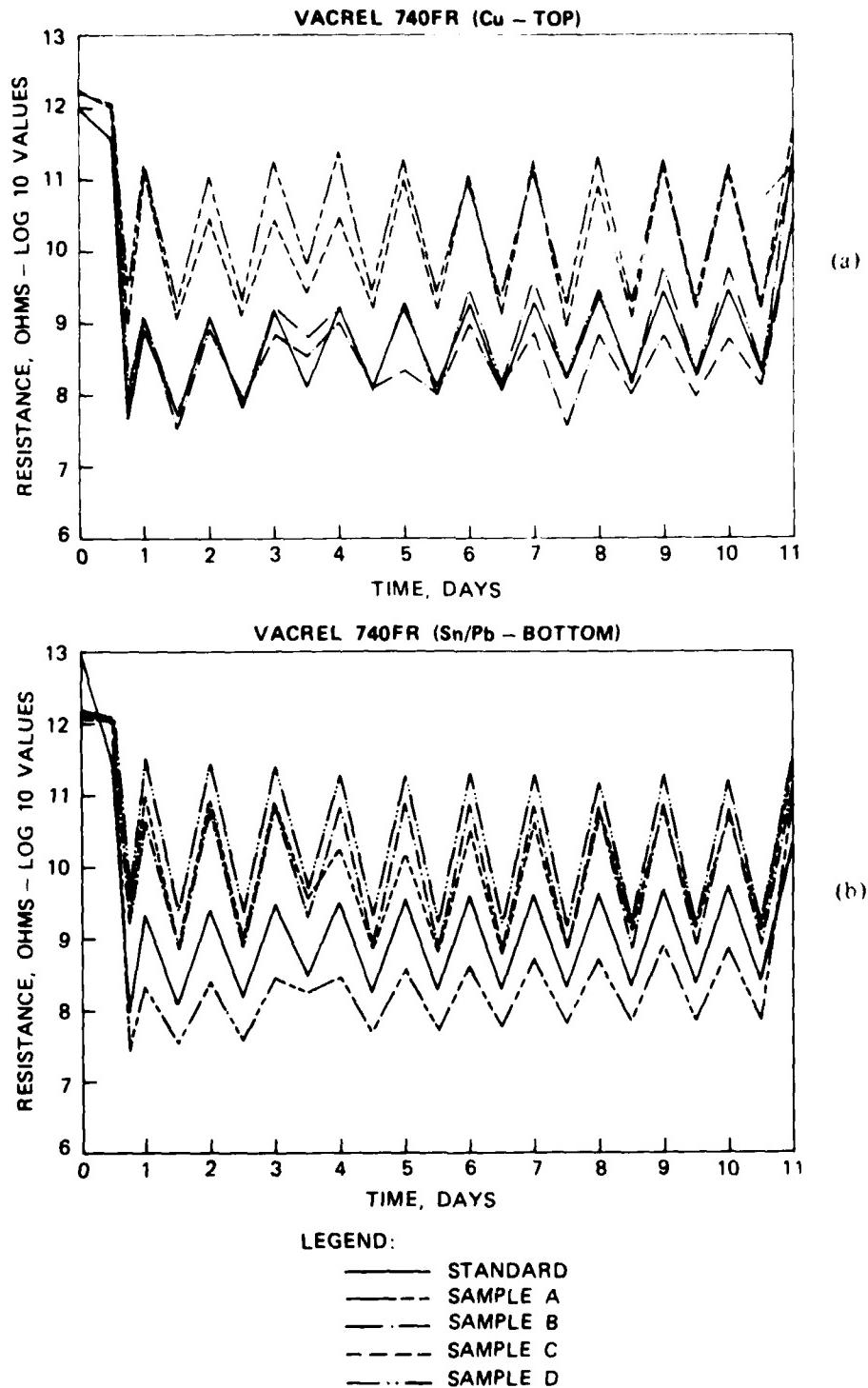


FIGURE 9. Vacrel 740FR, Resistance Values. (a) Copper (top).
(b) tin/lead (bottom).

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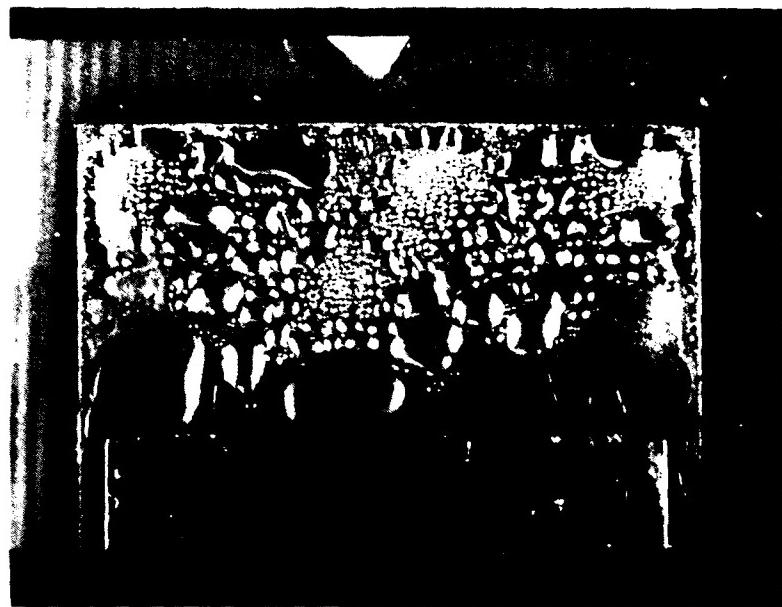


FIGURE 10. Vacrel 740S, Wrinkled Mask and Trapped Flux on Ground Plane.

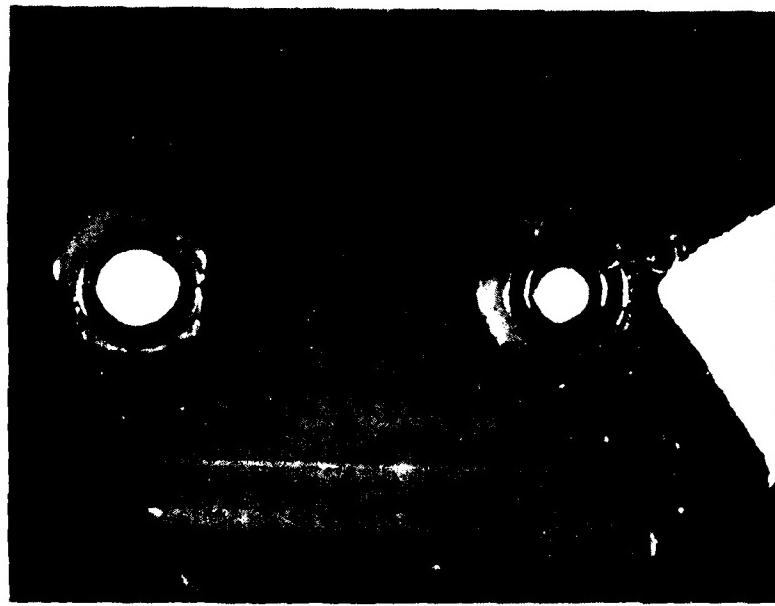


FIGURE 11. Vacrel 740S, Solder Mask in Plated-Thru-Holes Blocked Solder.

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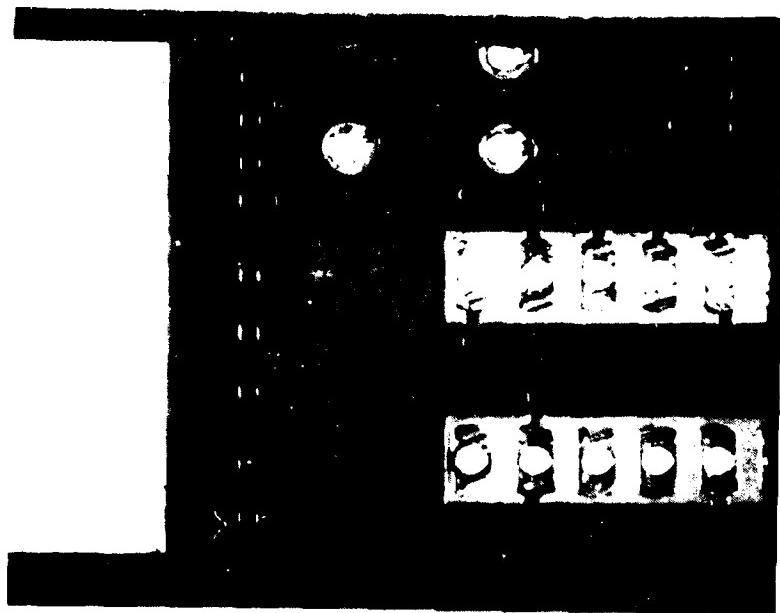


FIGURE 12. Vacrel 740S, Hot Air Levelling Process Caused Mask to Lift From Traces.

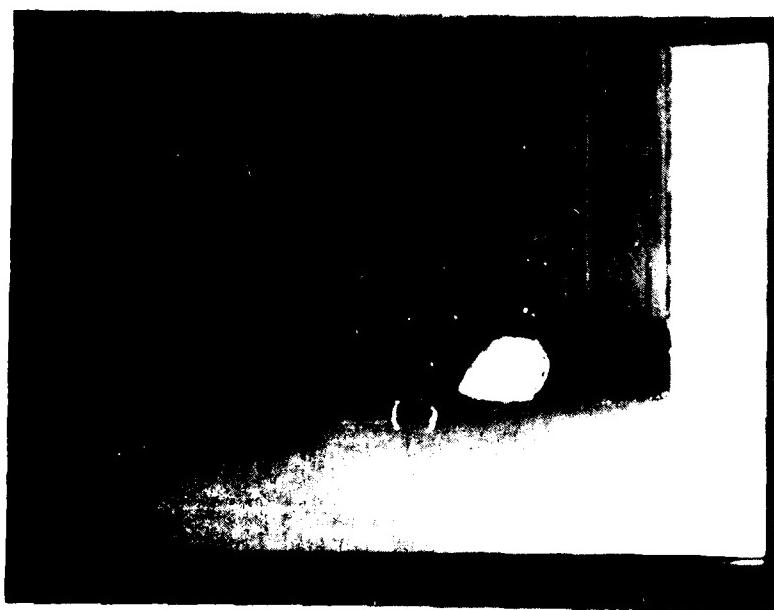


FIGURE 13. Vacrel 740S, Hot Air Levelling Process Caused Mask to Lift and Chip From Comply.

THIOKOL-DYNACHEM LAMINAR RM

Thiokol-Dynachem Laminar RM is a dry film solder mask that is developed in an aqueous process. The inspection at 20X before any tests were conducted showed a few inclusions and some dark spots on the metal surface. The edges around the pads were very smooth and clear though there was some slight misregistration on the pads. A mask thickness of 0.0046 inch on the ground plane, 0.0021 inch on the comb traces, and 0.0053 inch on the laminate was measured though the film thickness before application was 0.004 inch. The thickness difference before application and after application could be due to material swelling caused by the potting compound used to make the microsection.

Abrasion resistance was good; the surface could be scratched with only a 5H pencil hardness and 50 cycles of Taber abrasion showed some wear but not through to the traces. The punch test caused loss of adhesion of the mask on the ground plane of both the tin/lead and the copper boards and also on the laminate.

Adhesion on the copper surfaces was good with less than 5% loss from the cross-hatch test both before and after soldering. The cross-hatch test caused a loss of 15% on the tin/lead masked ground plane.

Two of the isopropyl alcohol-based fluxes loosened the Laminar RM from the laminate and the metal surfaces.

The solvent resistance test showed poor results. The mask softened or totally separated from the board surface in each of the solvents tested.

The electrical tests of Laminar RM gave a breakdown voltage of 2400 VAC before soldering and 2500 VAC after soldering and moisture/temperature cycling. Surface resistivity was 1×10^{13} ohms/square both before and after soldering and moisture temperature cycling.

The hydrolytic stability test caused no damage to the Laminar RM.

The hot solder dip caused no damage to the mask but there were some holes that did not accept solder.

Wave soldering of the Laminar RM copper boards caused excessive blistering of the mask across the entire bottom surface. See Figures 14 and 15. Blisters were concentrated around the pad openings but appeared in all areas, including the laminate and the 0.006-inch lines of the comb pattern. Probing the blisters caused the mask to chip off down to the copper surface. See Figure 16. Flux was trapped under the mask on the ground plane and along the entire length of the traces on the tin lead boards. See Figure 17. The tin lead boards had a few blisters on the bottom side, also. Smooth, even fillets formed on the pads that had been covered with misregistered mask on the edges.



FIGURE 14. Laminar RM, Wave Soldering Caused Blistering of Bottom Side of Copper Boards.

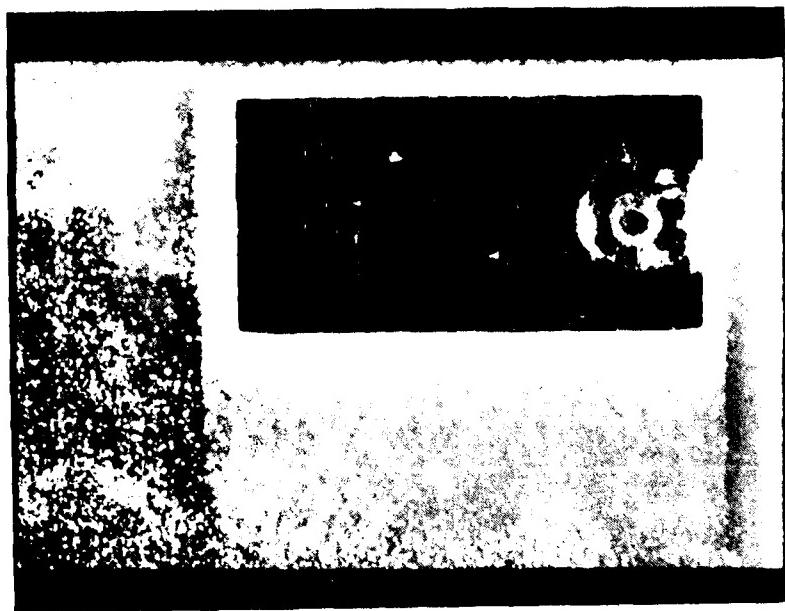


FIGURE 15. Laminar RM, Wave Soldering Caused Blistering of Bottom Side of Copper Boards.



FIGURE 16. Laminar RM. Mask Chipped Off of Copper Ground Plane.

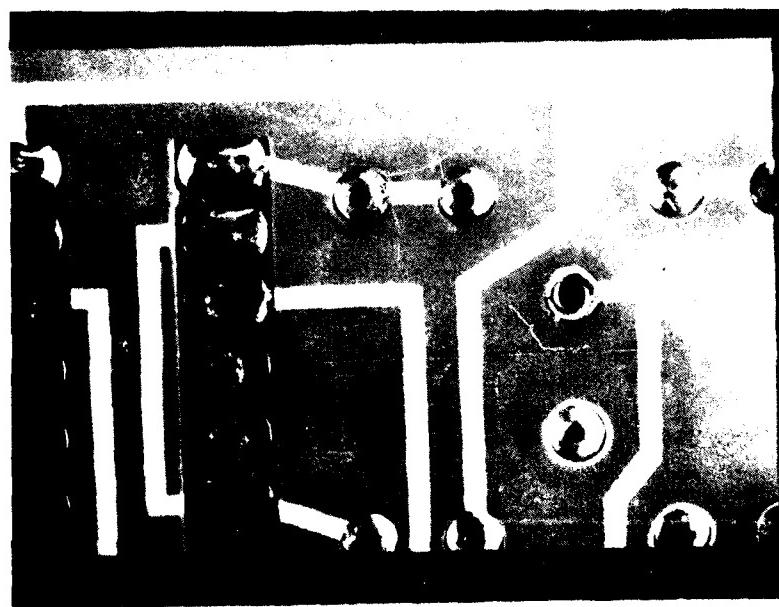


FIGURE 17. Laminar RM. Flux Trapped Under Mask on Traces.

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The cleanliness test solution caused the Laminar RM to separate from the laminate and the metal in many areas but flux remained trapped under the mask that had not separated. See Figures 18, 19, and 20. Probing easily flaked the mask off of the board. See Figure 21. Ionic contamination values were unacceptably high at an average of 15 micrograms/square inch.

In discussions with Thiokol personnel, it was learned that Laminar RM had been formulated to be removed by isopropyl alcohol. This mask, therefore, cannot be used for military electronics because of the isopropanol/water solution used in the cleanliness test.

The resistance readings for Laminar RM taken during the moisture/temperature cycling test were lower than the unmasked standard but were above the megohm range. See Figures 22 and 23. An explanation for the lower readings could be the board fabrication and processing variables in addition to the higher ionic level of the Laminar RM that would encourage a lower resistance between the traces of the comb. The very high resistance values for the tin/lead board (top) Sample B are probably due to board fabrication variations.

Inspection after moisture/temperature cycling showed flux trapped under the traces and some flux that had seeped out across the board. See Figure 24. The mask had also become brittle and was easily cracked.

Solder adhered to the Laminar RM sample boards that were hot air leveled. See Figure 25.

The excessive blistering on the bottom side of the wave soldered boards was thought by Thiokol personnel to be caused by a failure to properly cure this side. A set of IPC-B-25 copper boards masked by Thiokol was additionally tested. Also, two tin/lead and two copper boards from the original set were further cured for 75 minutes in a 300°F oven, then exposed to ultraviolet light for 5 minutes on each side.

The original boards that were additionally cured were not damaged by the hot solder dip, but the wave soldering process again caused excessive blistering on the bottom side of the board. Wrinkling and flux entrapment occurred on the top and bottom sides of the tin/lead boards. See Figure 26.

Cleanliness test ionic contamination levels were again above 10 micrograms square inch and the test solution caused the mask to separate as before. See Figure 27.

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FIGURE 18. Laminar RM Mask Loose and Cracked on "Y" Pattern.

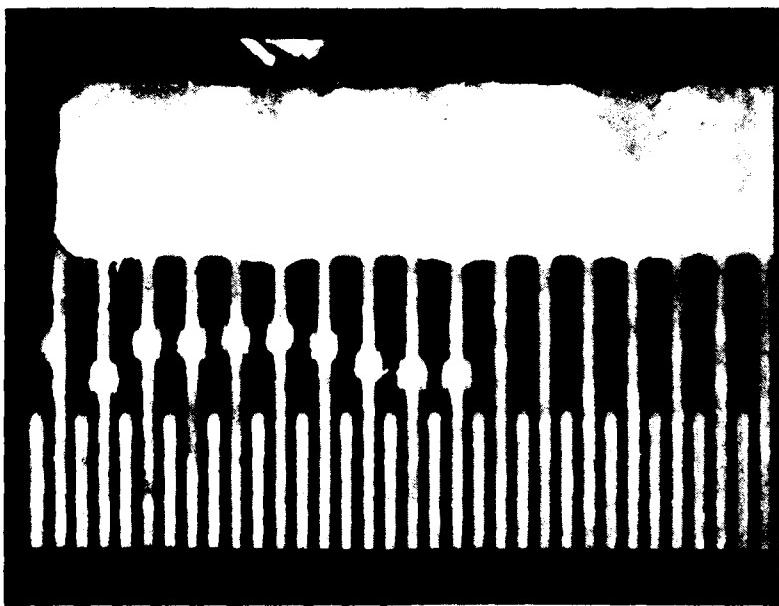


FIGURE 19. Laminar RM Mask Lifted and Blistered on Comb Pattern.

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FIGURE 20. Laminar RM Flux Trapped Under Mask on Ground Plane.

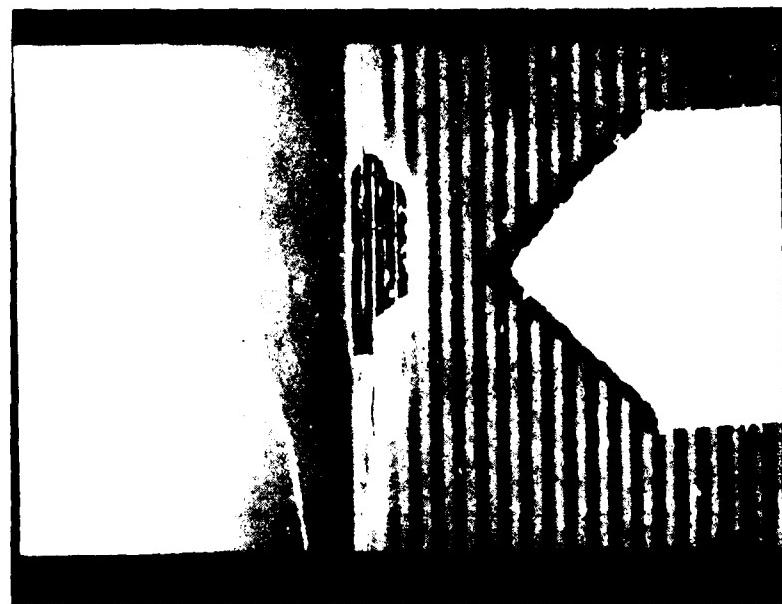


FIGURE 21. Laminar RM Mask Clipped Off of Comb Pattern.

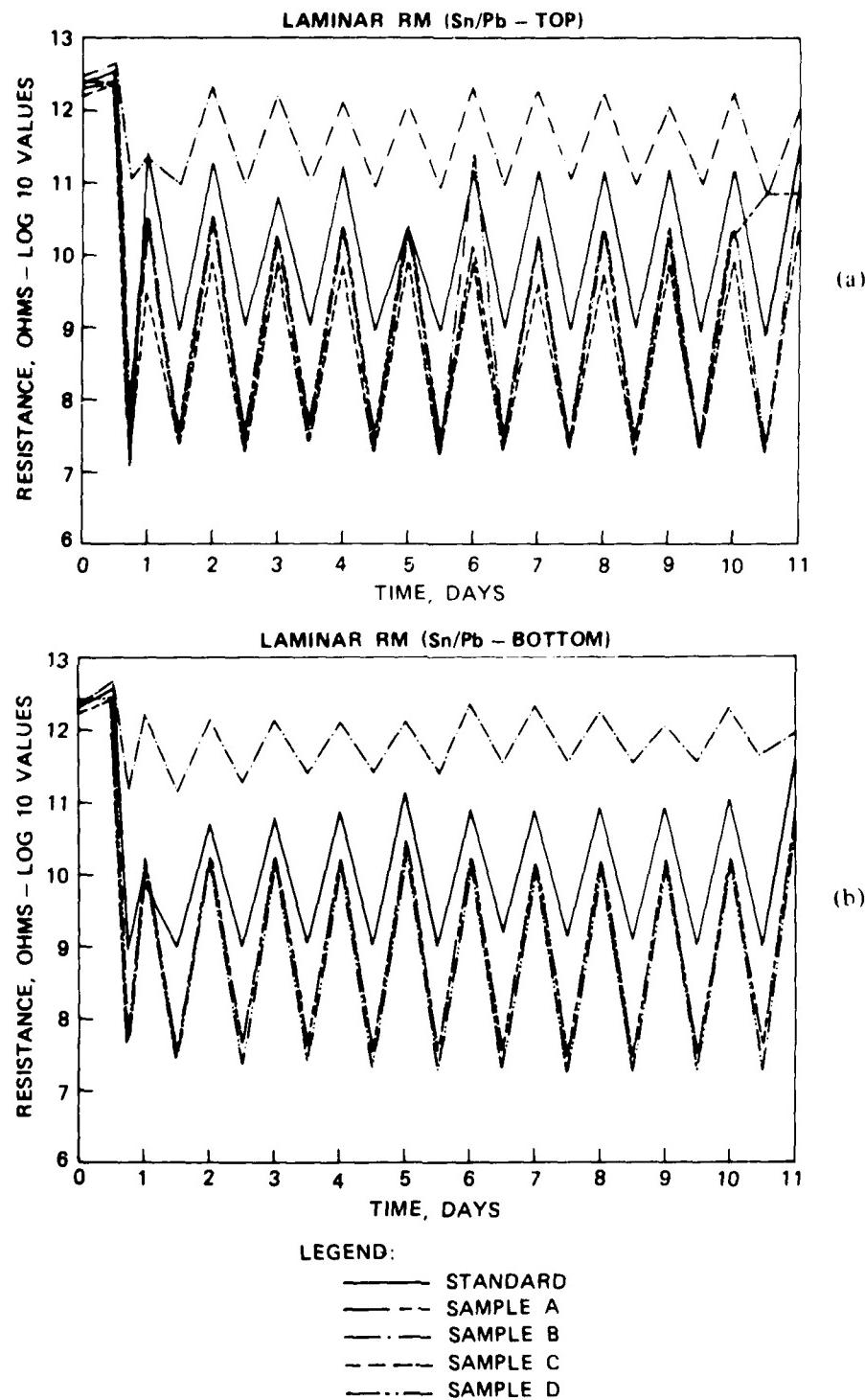


FIGURE 22. Laminar RM, Resistance Values, Tin/Lead.
(a) Top, (b) bottom.

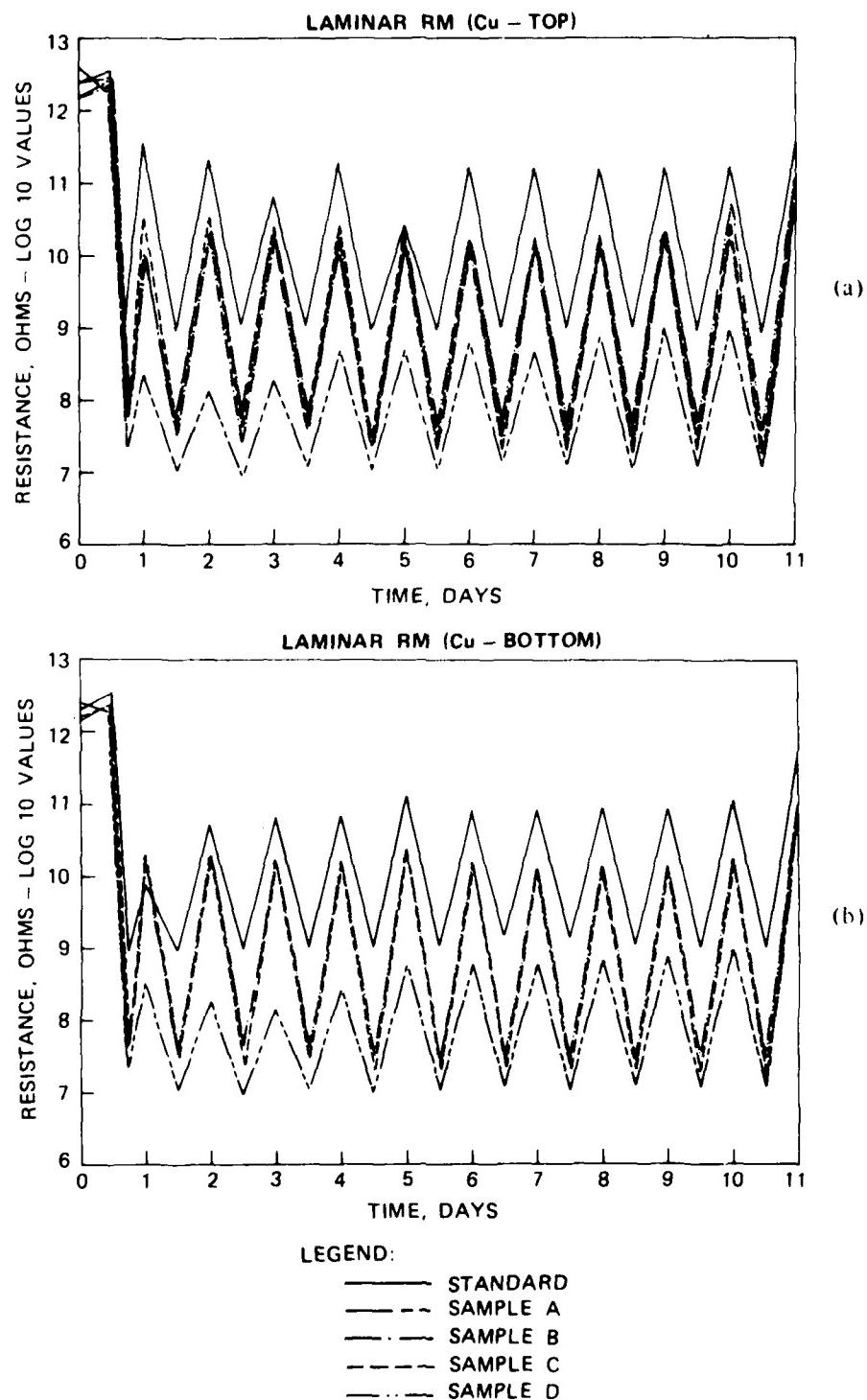


FIGURE 23. Laminar RM, Resistance Values, Copper.
 (a) Top. (b) bottom.

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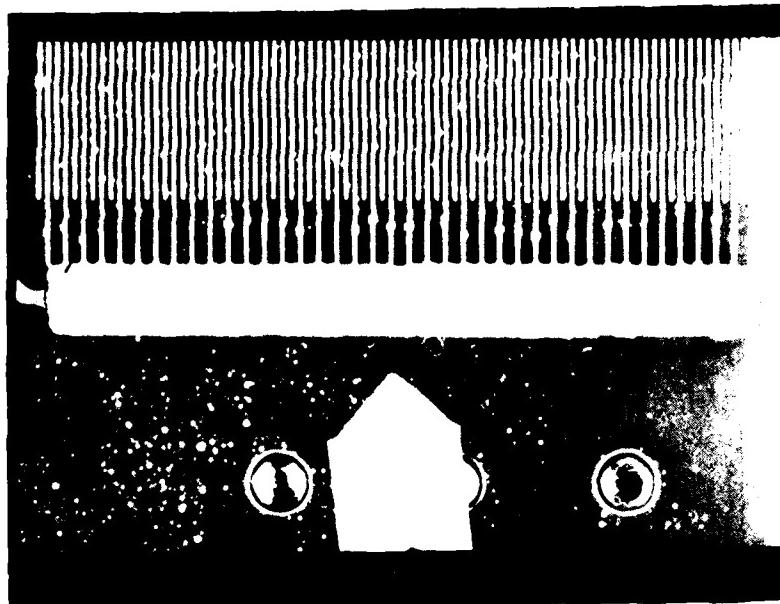


FIGURE 24. Laminar RM, Flux Trapped Under Mask on Comb Pattern.

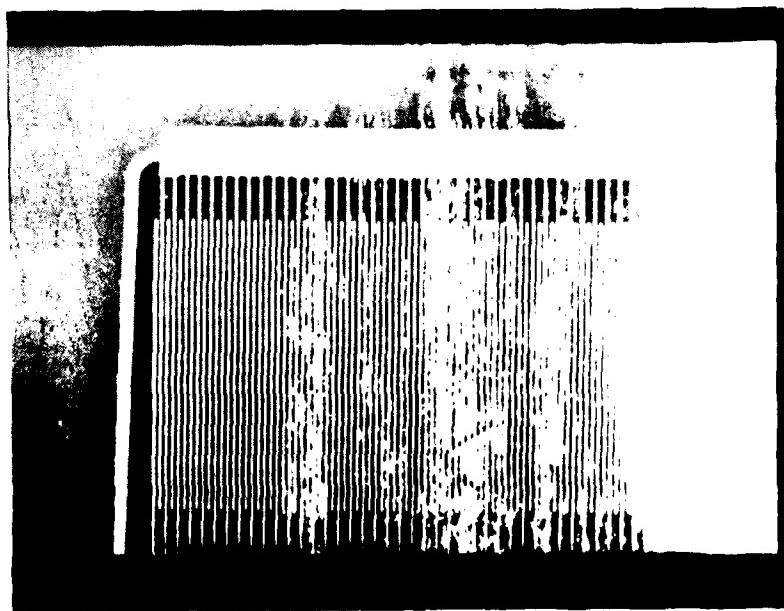


FIGURE 25. Laminar RM, Solder Remained on Mask After Hot Air Levelling Process.

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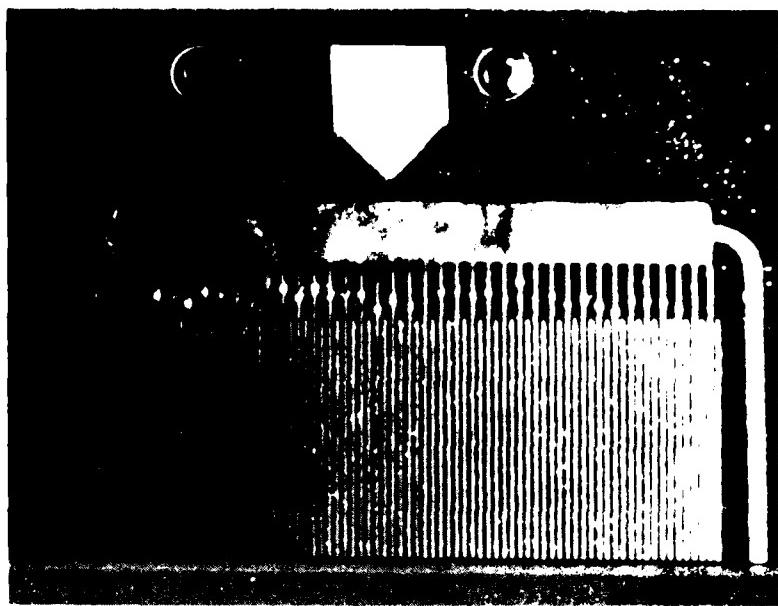


FIGURE 26. Laminar RM (Extra Cure). Mask Blistered on Bottom Side.

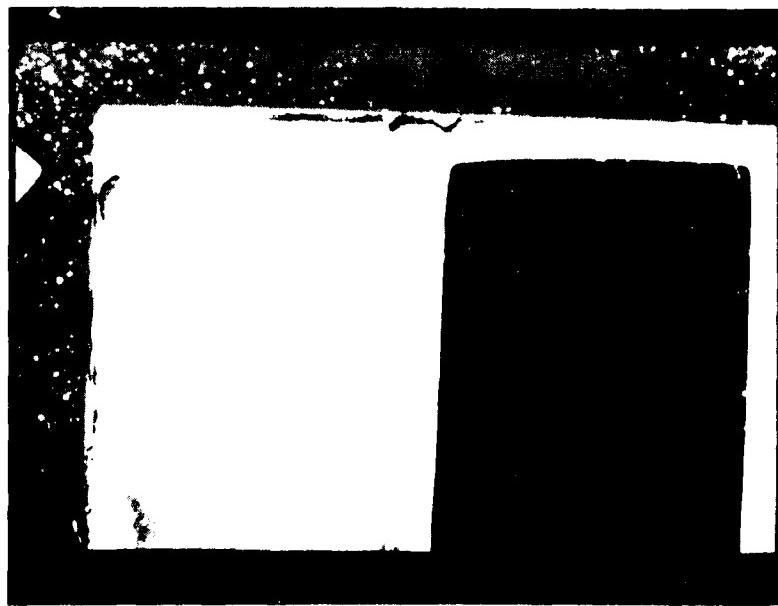


FIGURE 27. Laminar RM (Extra Cure). Cleanliness Test Caused Mask on Ground Plane to Crack.

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Moisture/temperature cycling resistance values were similar to the original tests although the standard had a lower resistance, probably due to board fabrication variations. See Figure 28. The breaks in the pattern are due to operator absence. The inspection after moisture/temperature cycling showed entrapped flux. The mis-registered mask on the pads had become brittle and chipped off of the board.

The Laminar RM appeared very thick on the IPC-B-25 boards supplied by Thiokol but measurements could not be made due to the limited amount of boards. The hot solder dip process caused excessive blistering on the top side of the copper boards. See Figure 29. The blisters chipped off of the board with handling. There were many areas of copper that would not accept solder. Close examination of these areas revealed small green particles that looked like "crumbs" of solder mask on the copper. See Figure 30. Wave soldering caused flux entrapment on the blistered top side but no problems on the bottom side.

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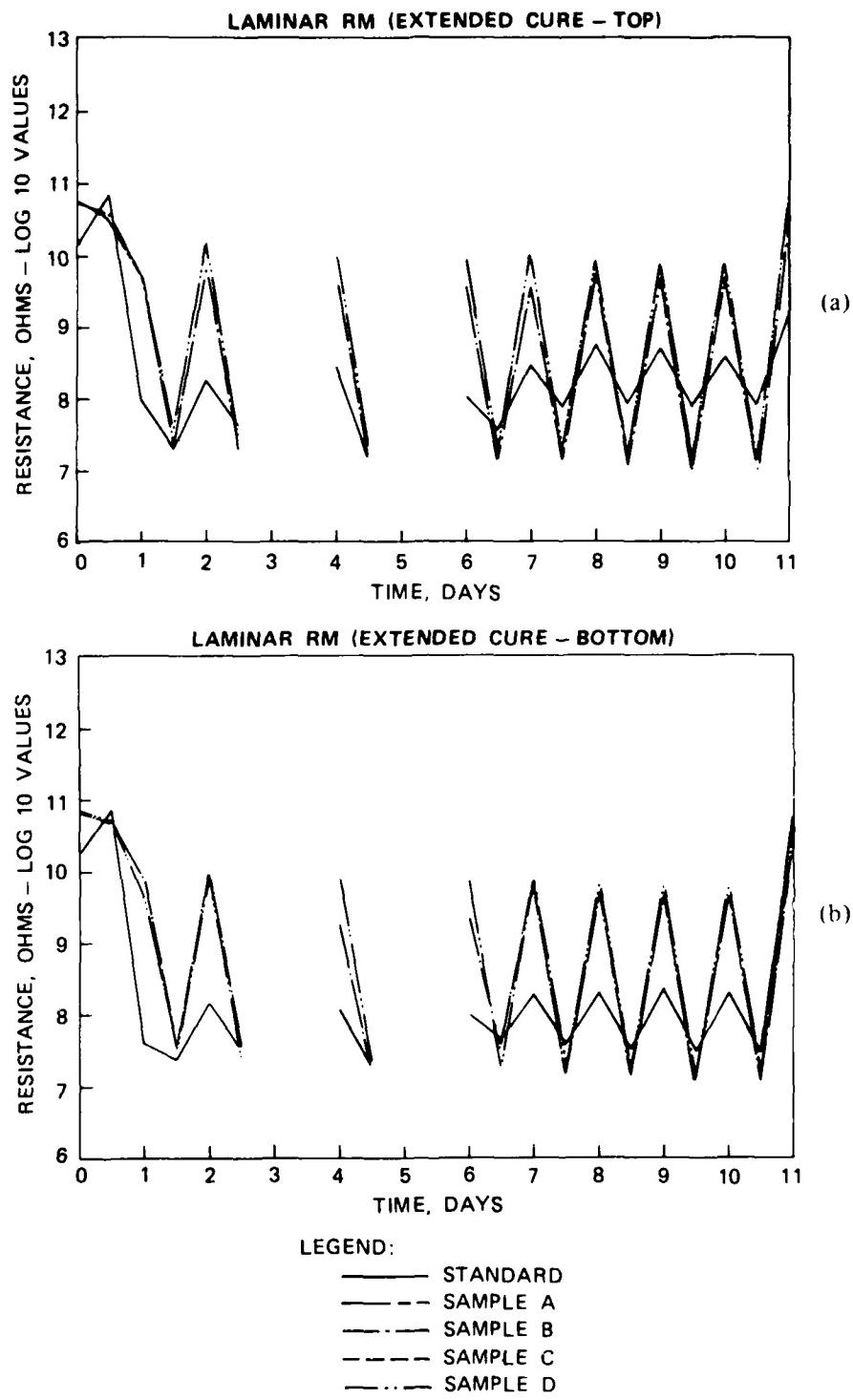


FIGURE 28. Laminar RM (Extra Cure), Resistance Readings.
(a) Top, (b) bottom.

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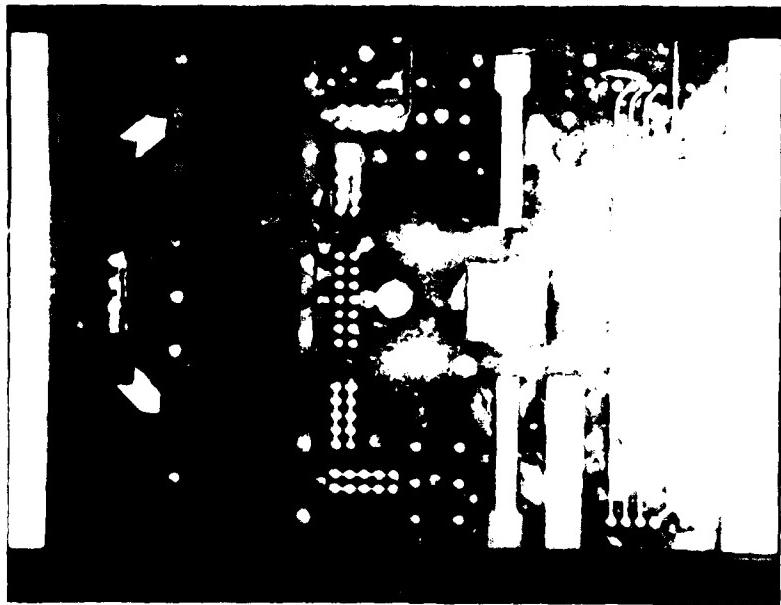


FIGURE 29. Laminar RM (IPC-B-25). Blisters on Top Side of Copper Board.

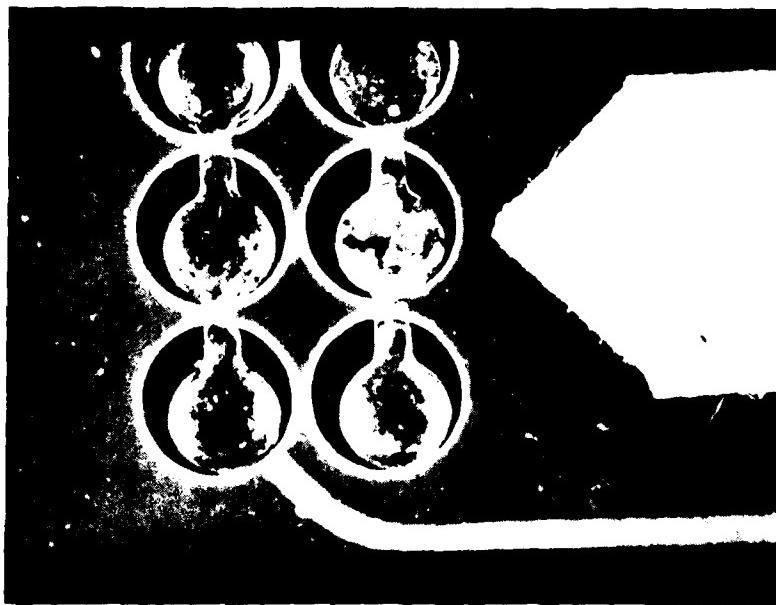


FIGURE 30. Laminar RM (IPC-B-25). Unsolderable Pad Due to Solder Mask Debris.

HYSOL SR1010 AND SR1000

The Hysol SR1010 and SR1000 solder masks are liquid screenable masks. The SR1010 has a higher solids content than the SR1000; therefore, it has different screening properties as well as different electrical properties. Masking of the Hysol SR1010 and SR1000 was performed by two separate companies.

Visual inspection before testing of SR1010 showed many voids, bubbles, and pinholes across the boards, inclusions, areas of thin and thick coverage, and irregular pad openings. The irregular pad openings were caused by a misalignment on the second pass of the squeegee. See Figures 31 and 32. A grid pattern from the screen was visible on the open area of some of the ground planes. See Figure 33.

The Hysol SR1000 showed some of the same problems: voids, bubbles, and pinholes on the comb pattern, ground plane, and in the 90-degree bend of traces in addition to inclusions. See Figures 34 and 35. The copper was visible in some areas due to the bubbles and pinholes.

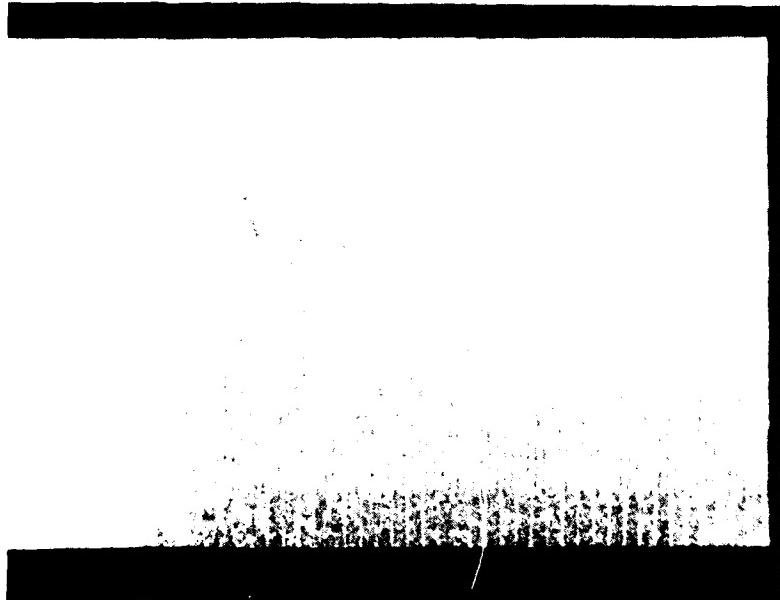


FIGURE 31. Hysol SR1010, Pinholes in Mask on Comb Pattern.

NWC-TP-6517

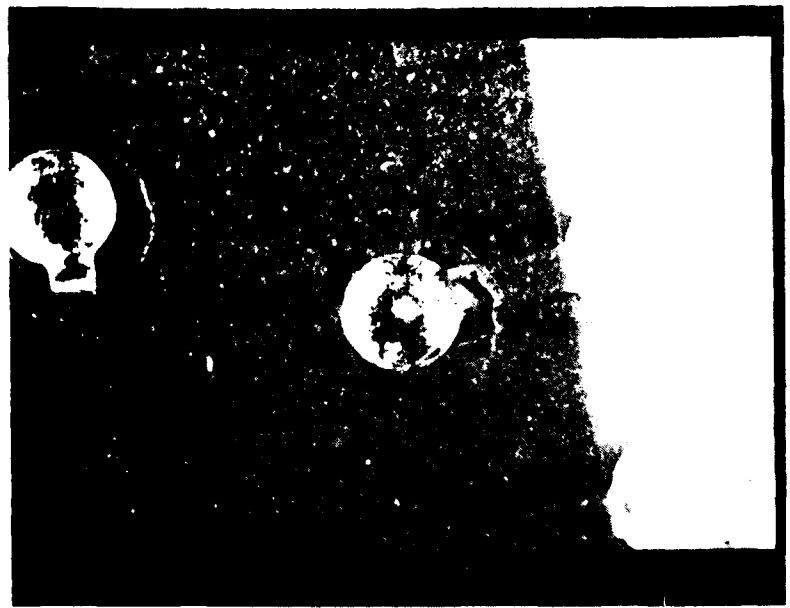


FIGURE 32. Hysol SR1010. Misregistration of Mask on Pads.



FIGURE 33. Hysol SR1010. Grid Pattern on Ground Plane.

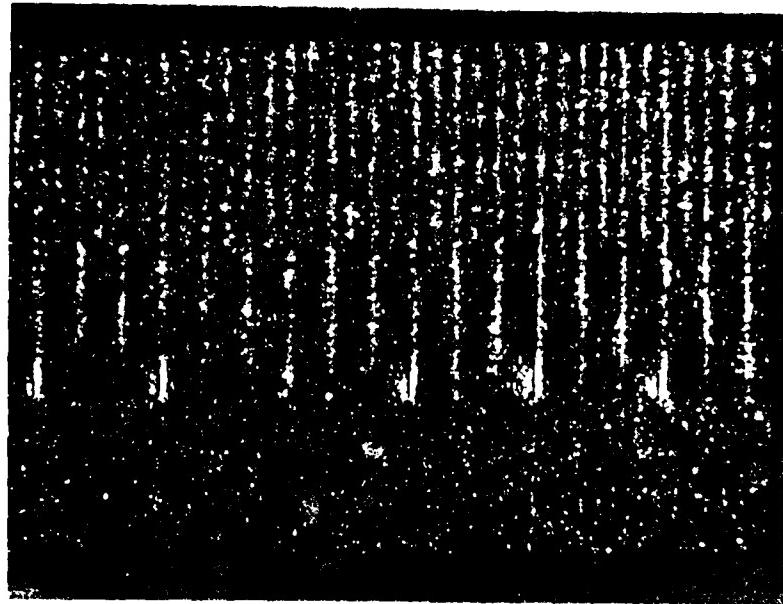


FIGURE 34. Hysol AR1000 Voids in Mask-on-Grid Pattern.



FIGURE 35. Hysol AR1000 Voids in Mask-on-Pendulum Circuit Trace.

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The success of a screened solder mask is greatly dependent on the process controls followed in the screening of the mask. The voids, bubbles, and pinholes seen on these boards are caused by the screening technique. Though screening does not provide pinhole-free coverage, careful control of the process can prevent the voids and bubbles that were seen on these samples. Poor preparation and workmanship can cause an acceptable solder mask to perform poorly under certain conditions. The marks on the ground plane were caused by an unclean screen and the inclusions were due to poor surface preparation.

The thickness of a screened solder mask is much less than that of a dry film solder mask. Hysol SR1000 had a thickness of 0.0015 inch on the ground plane, 0.0016 inch on the comb pattern traces, and 0.0039 inch on the laminate.

The mechanical properties of the two Hysol solder masks were similar. Both masks were scratched by only the 5H pencil hardness and were slightly worn by 50 cycles of Taber abrasion but not worn through to the metal surface. The adhesion was excellent over copper when tested by the cross-hatch test and the punch test before and after wave soldering for both masks. The tin/lead surface showed little loss (5%) on the cross-hatch test.

Neither the Hysol SR1010 nor the SR1000 were damaged by the fluxes.

Methylene chloride removed the mask from the tin lead surfaces but not from the copper or the laminate. DMSO softened the mask allowing it to be scraped away.

The breakdown voltages for the SR1010 and the SR1000 solder masks were low and inconsistent due to the pinholes across the ground plane. Hysol SR1010 had values of 1000 VDC and 500 VDC from two areas on the same board. The breakdown voltage was dependent on the location of the electrode since the mask coverage was so varied. After wave soldering, the value was 900 VDC for Hysol SR1010 and 800 VDC for Hysol SR1000. The coverage provided by a screened solder mask is not consistent enough to allow its use as an electrical insulating layer.

Hysol SR1010 had a surface resistivity of 5×10^{13} ohms square and SR1000 had a value of 4×10^{12} ohms square.

The hydrolytic stability test caused no damage to either mask.

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The hot solder dip process did not damage the mask. In areas where the Hysol SR1000 mask bled or smeared onto the pads, solder was not accepted. Copper was visible in these areas because there was a very thin layer of resin that was enough to prevent wetting of the copper, but not enough protection to prevent oxidation during storage. See Figure 36.

The wave soldering process caused wrinkling of both masks over the tin lead. In areas where misregistration allowed solder mask onto the pad, the fillets were deformed. Flux was trapped under the wrinkled mask in the ground plane and along traces for one-quarter inch from the opening. See Figures 37 and 38. The traces were wrinkled on both the top and bottom sides of the boards and after 24 hours, the flux could be seen near the edges of the traces where it had seeped from under the wrinkled mask. See Figure 39.

The cleanliness test for ionic residue gave passing results at 1.7 micrograms square inch for Hysol SR1010 and 0.42 microgram/square inch for Hysol SR1000. An inspection of the Hysol SR1000 after cleanliness testing revealed flux remaining in most areas and brittle mask that easily cracked.

Resistance readings for Hysol SR1010 taken during the moisture/temperature cycling were generally lower than the standard but still in the acceptable range. See Figures 40 and 41. Due to the pinholes across the comb pattern, the insulating quality of screened solder mask is not as good as dry film solder mask. Inspection after cycling showed trapped flux remaining.

Resistance values for Hysol SR1000 were similar to Hysol SR1010 except that the standard had a lower value. After cycling the SR1000, the wrinkled mask easily chipped off of the metal surfaces.

Hot air leveling caused no damage to the Hysol SR1010.

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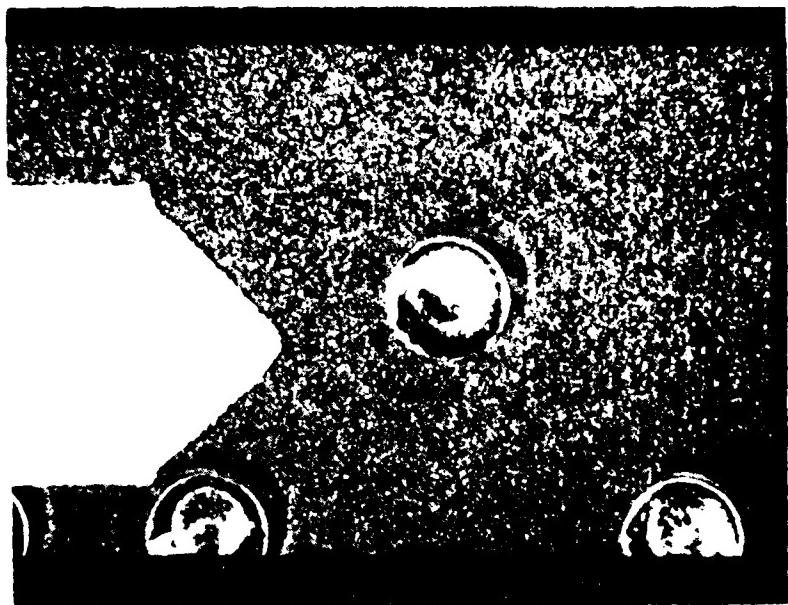


FIGURE 36. Hysol SR1000. Mask Bleed Residue on Pad
Caused Non-Wetted Copper.



FIGURE 37. Hysol SR1000. Flux Trapped Under Wrinkled
Mask on Ground Plane.

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FIGURE 38. Hysol SR1010, Flux Trapped Under Wrinkled Mask on Ground Plane.

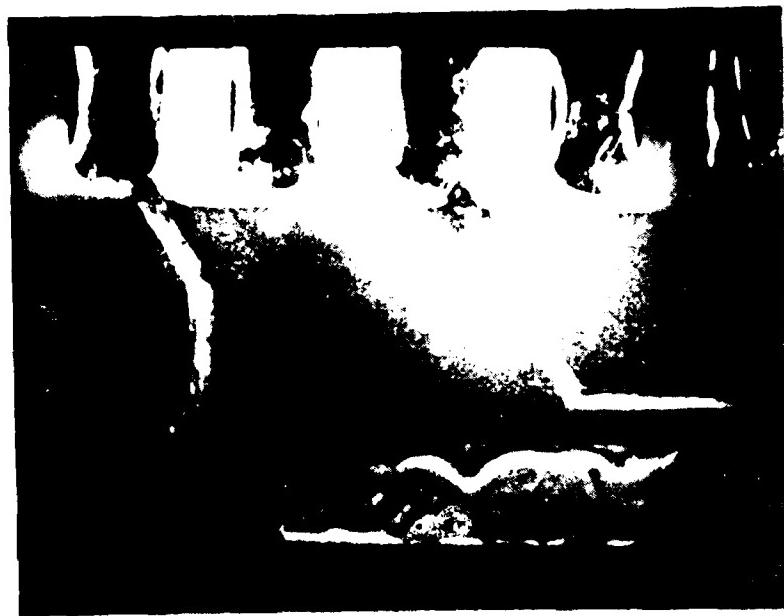


FIGURE 39. Hysol SR1010, Flux Seeped Out From Under Wrinkled Mask.

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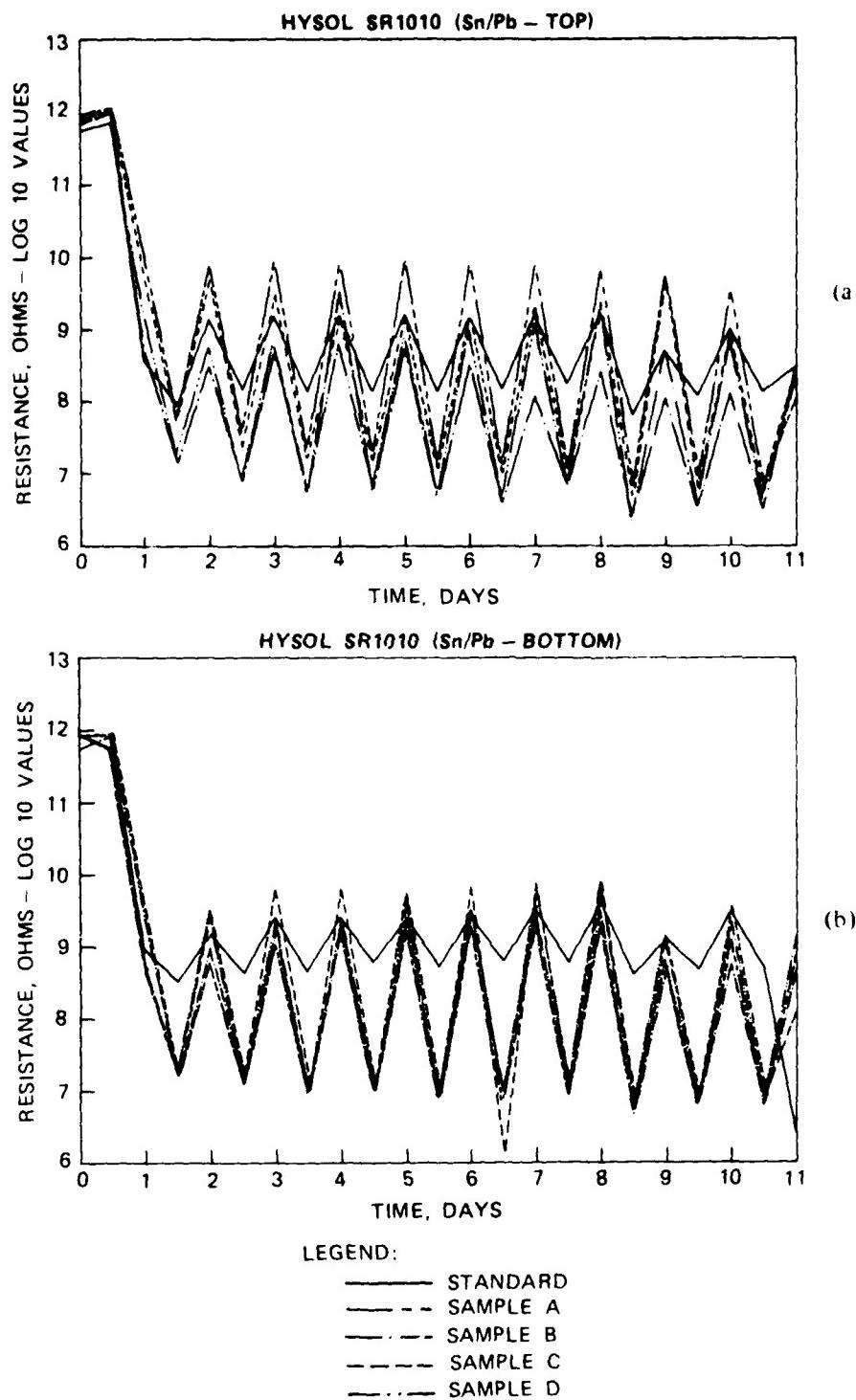


FIGURE 40. Hysol SR1010. Resistance Readings, Tin/Lead.
(a) Top. (b) bottom.

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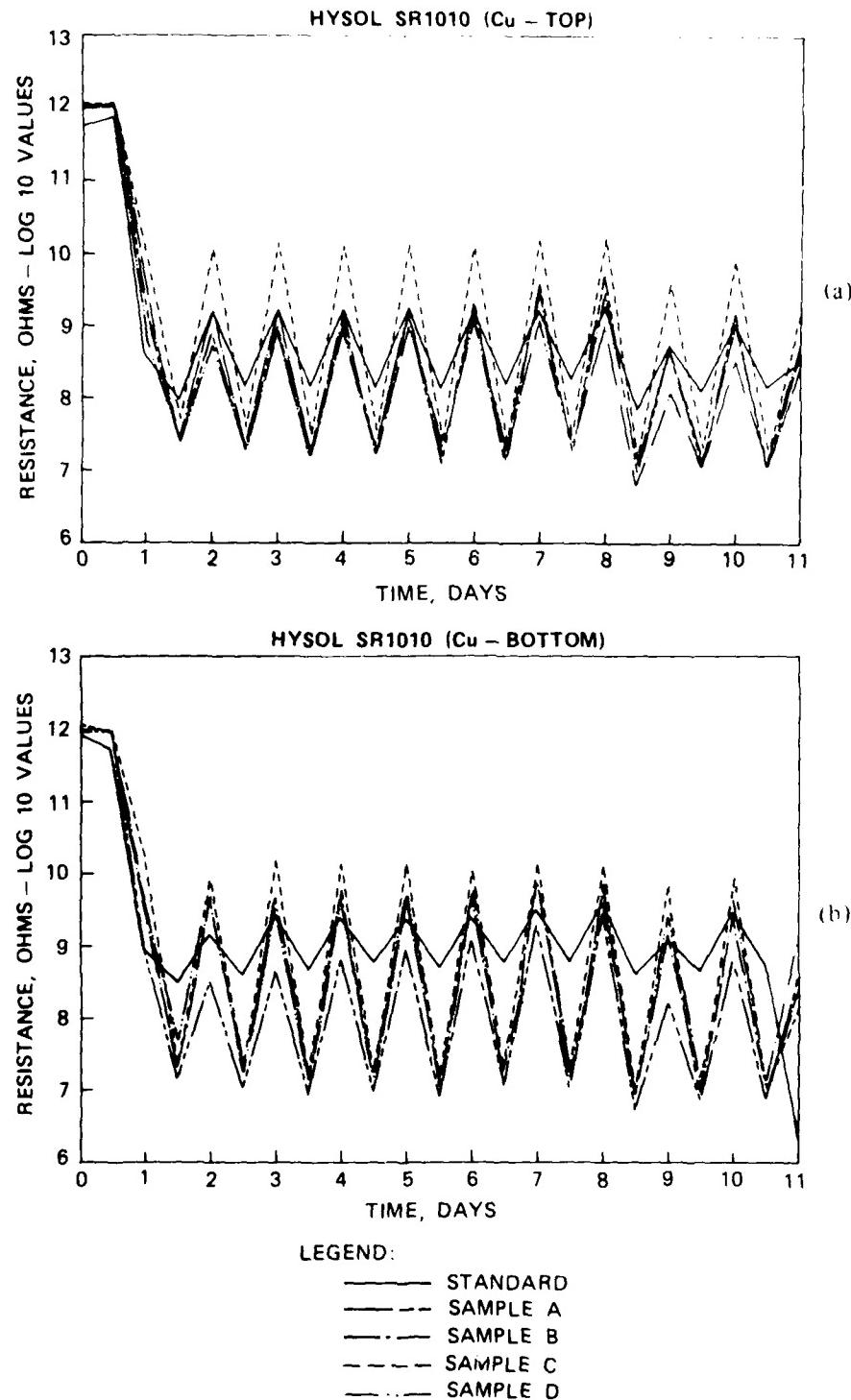


FIGURE 41. Hysol SR1010, Resistance Readings, Copper.
(a) Top, (b) bottom.

LONCO 222-M

An analysis of the profile of the profile of the film of bubbles was made in Figures 42 and 43. The resin onto the glass fiber coating infiltrated the film. Figure 44. Masked film on undiluted S-100. The bends in the film S-100 have been eliminated.

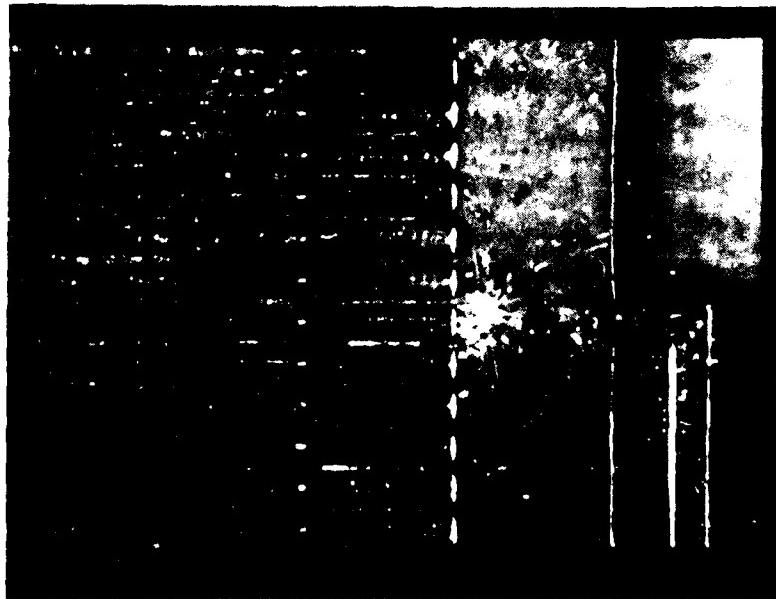


FIGURE 42. Lanco 222-M. Bubbles in Mask on Comb Pattern.

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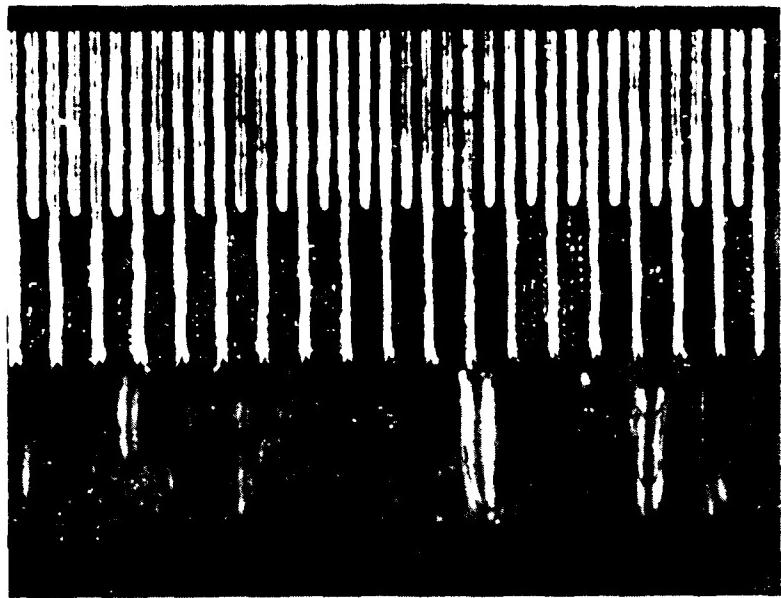


FIGURE 43. Lonco 222-M, Bubbles in Mask and Flux Trapped on Comb Pattern.



FIGURE 44. Lonco 222-M, Mask Bleed Residue Caused Non-Wetted Copper.

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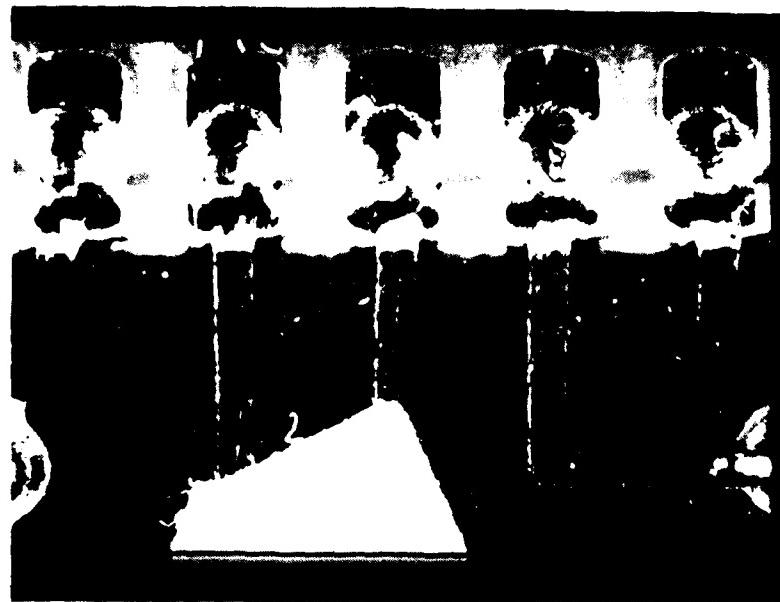


FIGURE 45. Lonco 222-M, Mask Bleed onto Traces and Laminate.

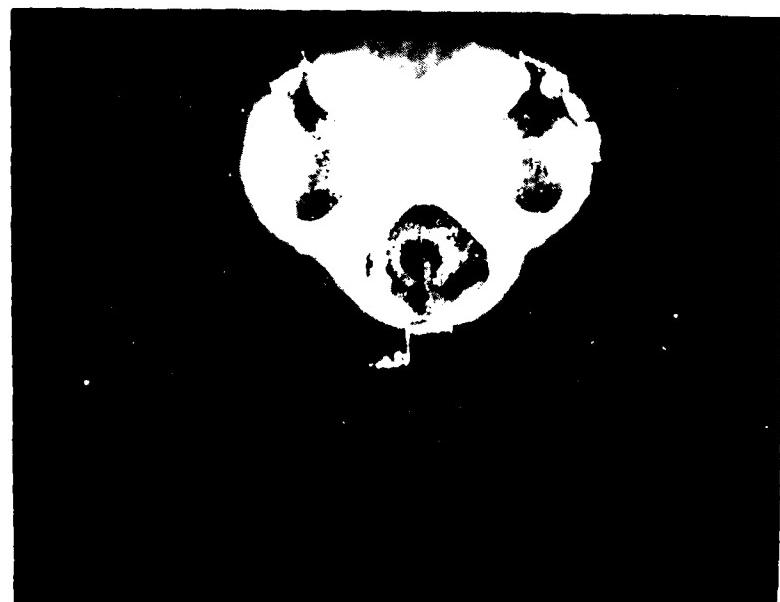


FIGURE 46. Lonco 222-M, Void in Mask at Bend in Circuit Trace.

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Properties of the Lonco 222-M solder mask were varied due to the quality of the mask application. The thickness of the mask over the ground plane was 0.0012 inch. This is a very thin coating to be relied upon for adequate protection against abrasion, dielectric breakdown, and environmental cycling. The mask may have had an inadequate viscosity during the screening process, thus depositing only a very thin layer of solder mask.

The surface of the Lonco 222-M mask was scratched with only the 5H pencil hardness, but 50 cycles of Taber abrasion showed wear down to the traces. The wear was probably due to the thin coating. The punch test did not damage the copper covered traces but did cause loss of adhesion on the tin/lead areas both before and after soldering.

Adhesion was good on the copper surface for both the tape and the cross-hatch tests. The tape test did not affect the mask on tin/lead but the cross-hatch test removed 100% of the mask.

The Lonco 222-M was not damaged by either the flux tests or the solvent tests.

The breakdown voltage of the Lonco 222-M was 650 VDC due to pinholes in the mask. The surface resistivity of the mask was 5×10^{12} ohms/square.

The hydrolytic stability test did not damage the Lonco 222-M.

The hot solder dip revealed the problem associated with the bleed of the mask onto the pad area as shown in Figure 44. The copper did not accept solder because of the film of resin that covered it.

Wave soldering of the Lonco 222-M solder mask caused the mask to separate from the tin/lead ground plane and allowed flux to be trapped under the mask that remained. See Figures 47 and 48. The flux under the mask seeped out later, leaving flux residue near the pad openings.

Cleanliness testing results were acceptable with an average of 0.35 microgram square inch. An inspection after testing revealed that flux was still trapped under the mask on the ground plane. See Figure 49. Also, the misregistered Lonco 222-M on the sides of the fillets had lifted and were easily chipped off of the surface.

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FIGURE 47. Lonco 222-M. Mask Lifted From Ground Plane and Trapped Flux.

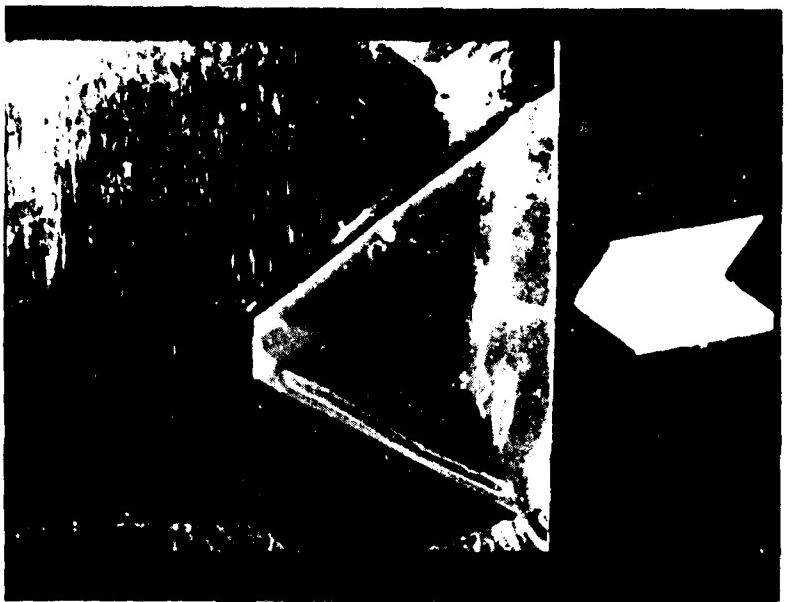


FIGURE 48. Lonco 222-M. Mask Lifted From Ground Plane and Trapped Flux.



FIGURE 49. Lonco 222-M, Flux Trapped Under Mask on Ground Plane.

Resistance measurements of the Lonco 222-M taken during the moisture/temperature cycling test were all lower than the standard unmasked board. See Figures 50 and 51. Because of pinholes throughout, the coating probably absorbed moisture, thus allowing the resistance to decrease. The wave soldered side of one tin/lead board had values in the megohm range which is considered to be a failure. This failure is believed to be due to the porosity of the mask caused by the application procedure.

A visual inspection after cycling showed slight oxidation of the copper areas that were covered by the thin film of resin that had bled from the mask edge. See Figure 52. Also, the mask on the tin/lead ground plane had become brittle.

The hot air leveling process did not damage the Lonco 222-M.

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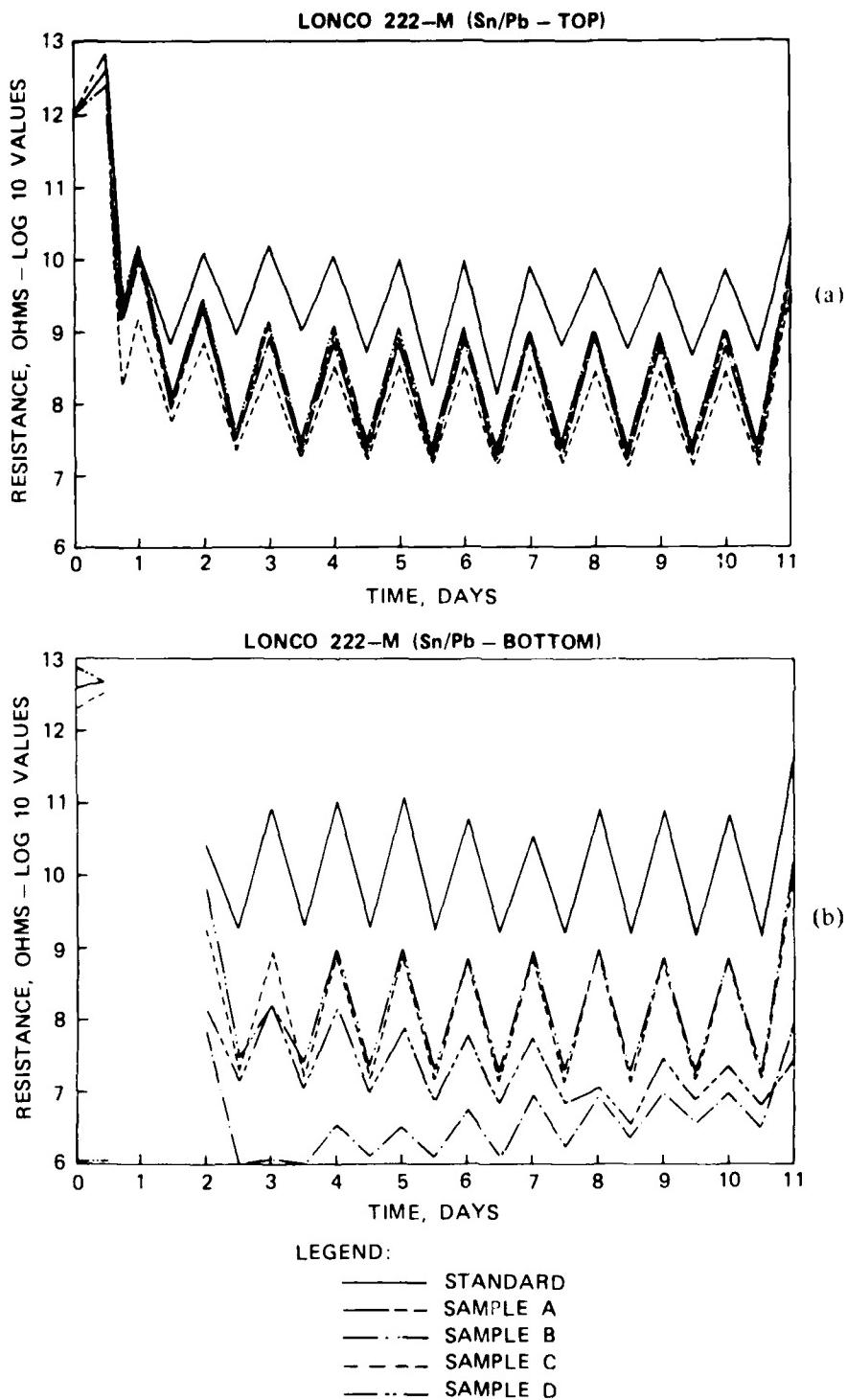


FIGURE 50. Lonco 222-M, Resistance Readings, Tin/Lead.
(a) Top. (b) bottom.

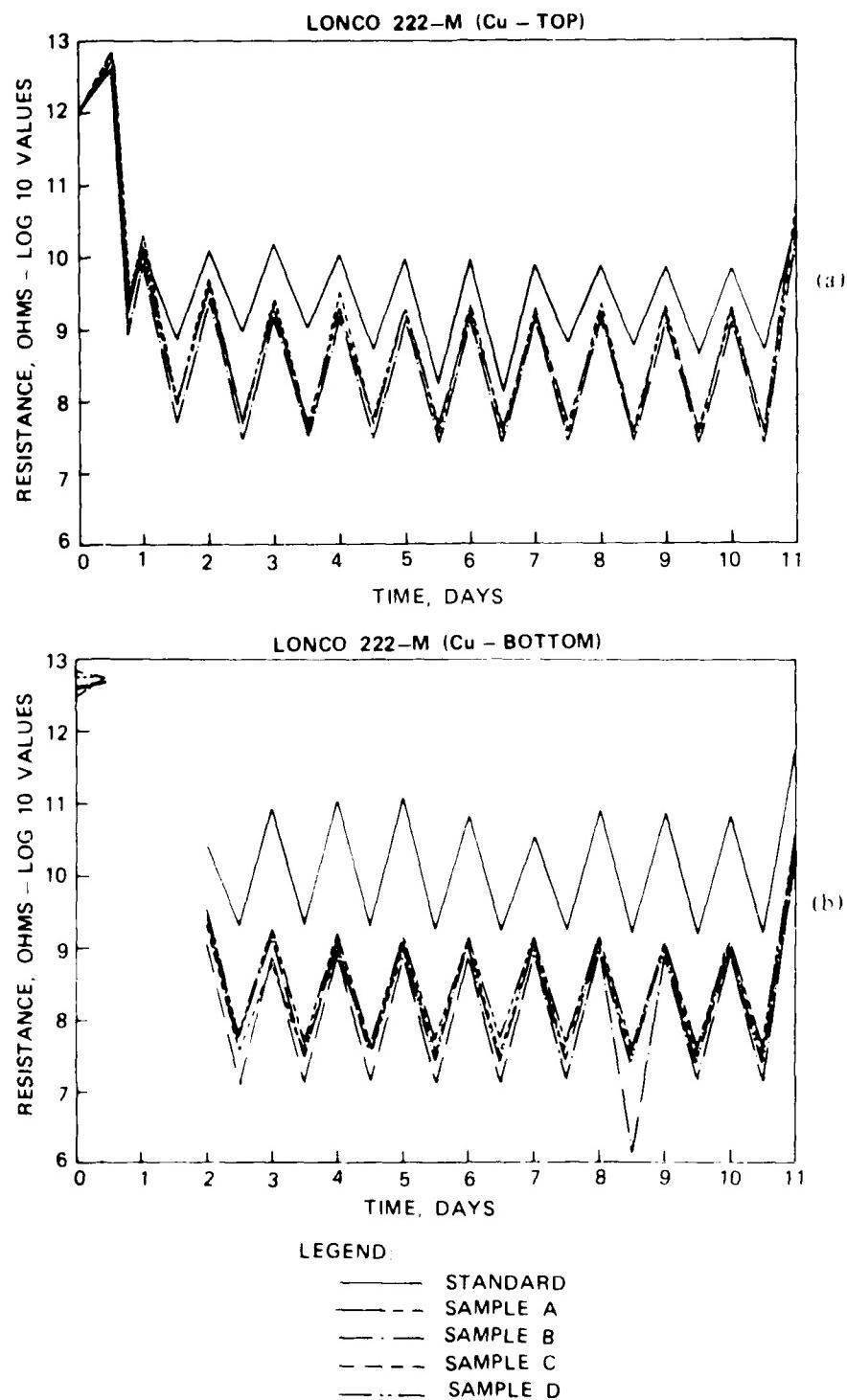


FIGURE 51. Lonco 222-M, Resistance Readings, Copper.
(a) Top, (b) bottom.

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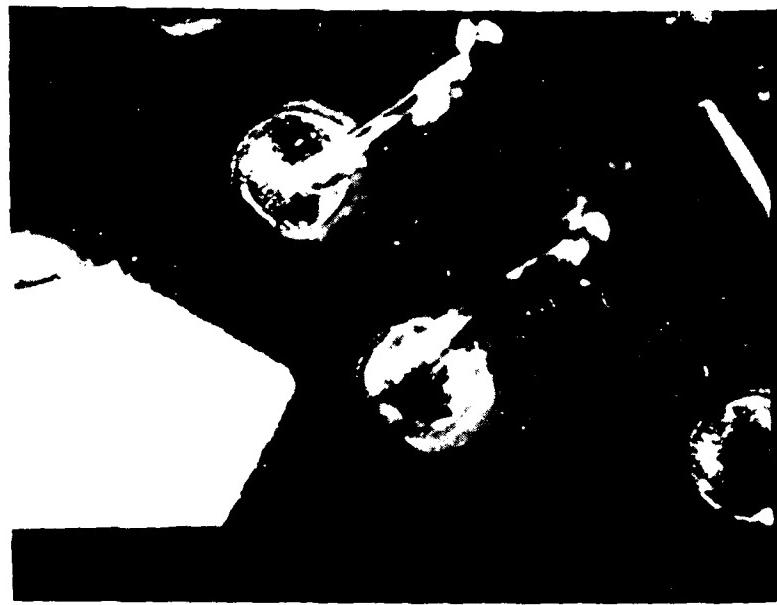


FIGURE 52. Lonco 222-M. Oxidized Copper Under Resin Film.

MACDERMID, Inc.

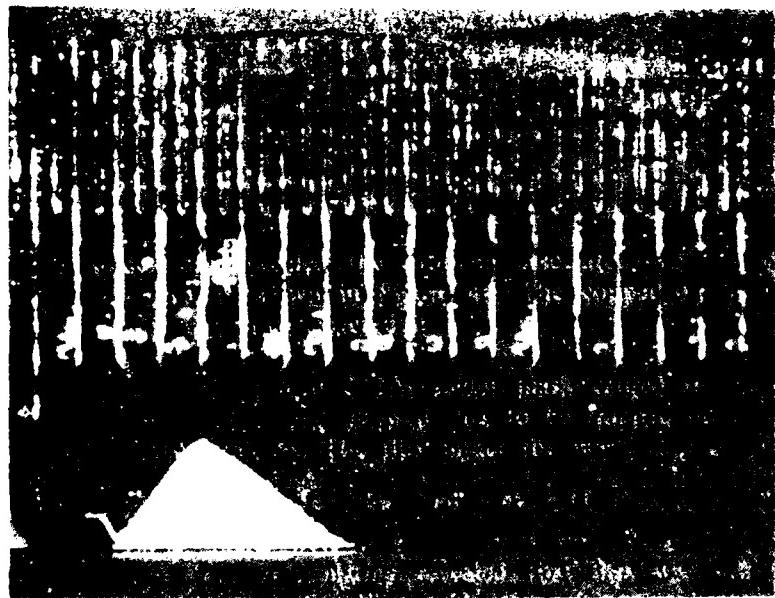


FIGURE 1. Measurement of the film thickness
of a polyester.

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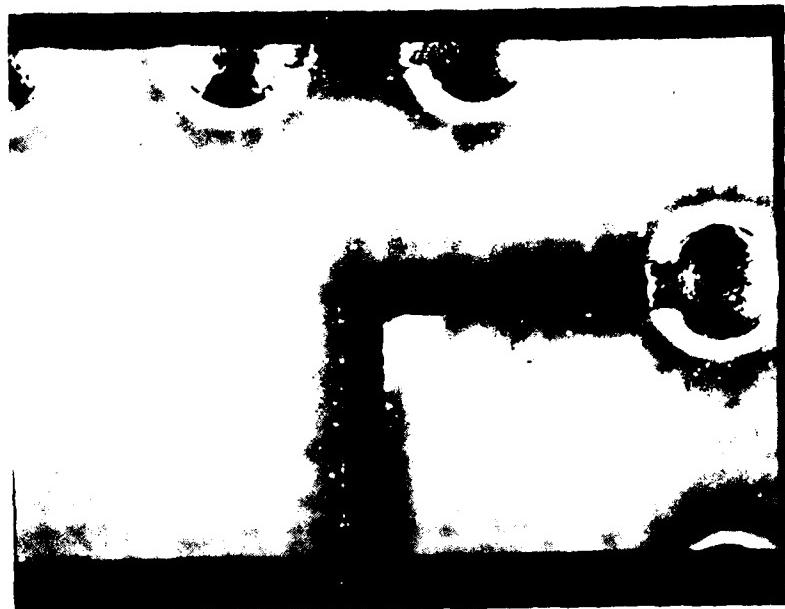


FIGURE 54. MacDermid 9446. Void in Mask at Bend in Circuit Trace.

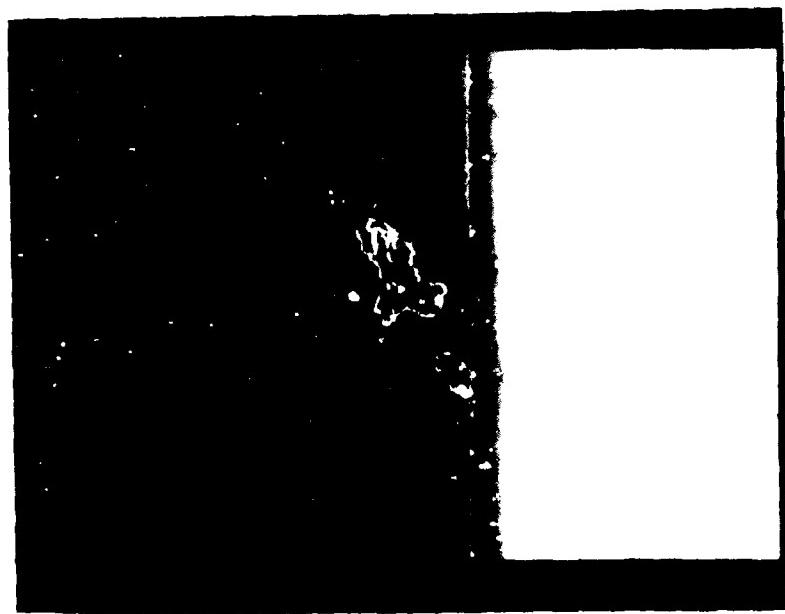


FIGURE 55. MacDermid 9446. Contamination Caused Mask to Lose Adhesion.

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FIGURE 56. MacDermid 9446. Unsolderable Copper Caused by Unclean Screen.

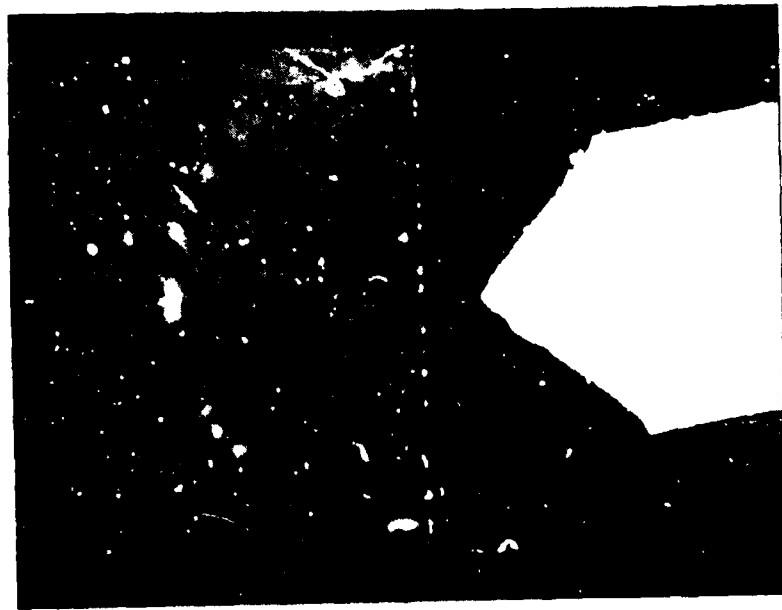


FIGURE 57. MacDermid 9446. Circular Pattern of Bubbles Caused Unsolderable Copper.

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The thickness of the MacDermid 9446 was 0.0015 inch on the ground plane.

The surface of the MacDermid 9446 was scratched by a 5H pencil hardness. Fifty cycles of Taber abrasion showed little wear of the mask. The punch test did not damage the mask over the copper surface, but did cause loss of adhesion of the mask over the tin/lead ground plane after wave soldering.

The adhesion of the mask to the copper was excellent on both the tape and the cross-hatch adhesion tests. The cross-hatch test caused 100% loss of the MacDermid 9446 over the tin/lead ground plane.

The fluxes caused no damage to the mask.

The only solvent to cause damage to the MacDermid 9446 was methylene chloride; this caused a slight wrinkling of the mask over both types of metal surfaces.

The breakdown voltage of the MacDermid 9446 was higher than the other screenable solder masks with a value of 1900 VDC before soldering and 1600 VDC after soldering. The electrode was carefully placed on the ground plane in an area where the circular pattern of bubbles did not cover. See Figure 57. The surface resistivity of the mask was 3×10^{12} ohms/square.

The hydrolytic stability test caused no damage to the MacDermid 9446 solder mask.

The hot solder dip revealed, as it did on the other screenable solder masks, the thin film of resin that had bled onto the pad areas causing the copper not to wet with solder.

Wave soldering of the MacDermid 9446 was accomplished on a Technical Devices dry wave solder machine due to equipment scheduling conflicts. The parameters were the same as those used on the other solder mask samples: 500°F solder temperature, spray flux with Alpha 611F, 180°F top side laminate preheat temperature, and a 2-second dwell in the wave.

The inspection after wave soldering showed trapped flux in the wrinkles of the MacDermid 9446 over the tin/lead plating. See Figure 58. The mask on the 0.006-inch traces of the comb pattern were wrinkled and the mask along the ground plane was rolled back on itself. See Figure 59.

Cleanliness testing showed a low amount of ionic contamination with an average of 1.0 microgram/square inch. The visual inspection after testing showed trapped flux and mask chipped off of the traces.

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FIGURE 58. MacDermid 9446, Flux Trapped Under Solder Mask on Ground Plane.



FIGURE 59. MacDermid 9446, Mask on Ground Plane Rolled Back by Soldering Process.

NWC TP 6517

The resistance measurements taken during the moisture/temperature cycling show passing values for the MacDermid 9446. See Figures 60 and 61. All of the resistance values were similar to the unmasked standard board except the comb patterns on the top side of the tin/lead boards. This unusual pattern is unexplained except for the high reading on Day 4 that is suspected to be an operator error in recording the exponent value of the resistance.

The hot air leveling process caused some blisters on the comb pattern and on some traces. See Figure 62.

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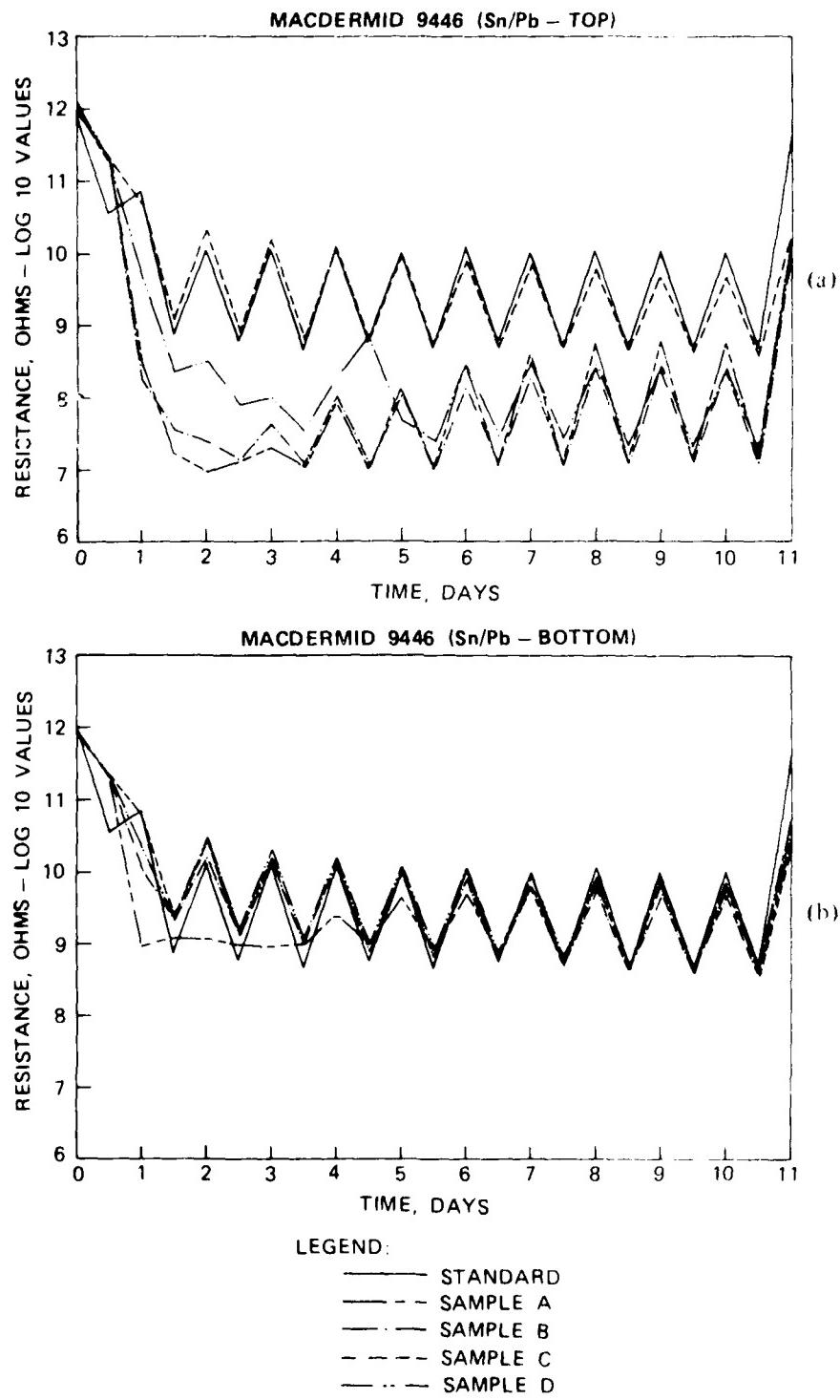


FIGURE 60. MacDermaid 9446, Resistance Readings, Tin/Lead.
(a) Top, (b) bottom.

NWC TP 6517

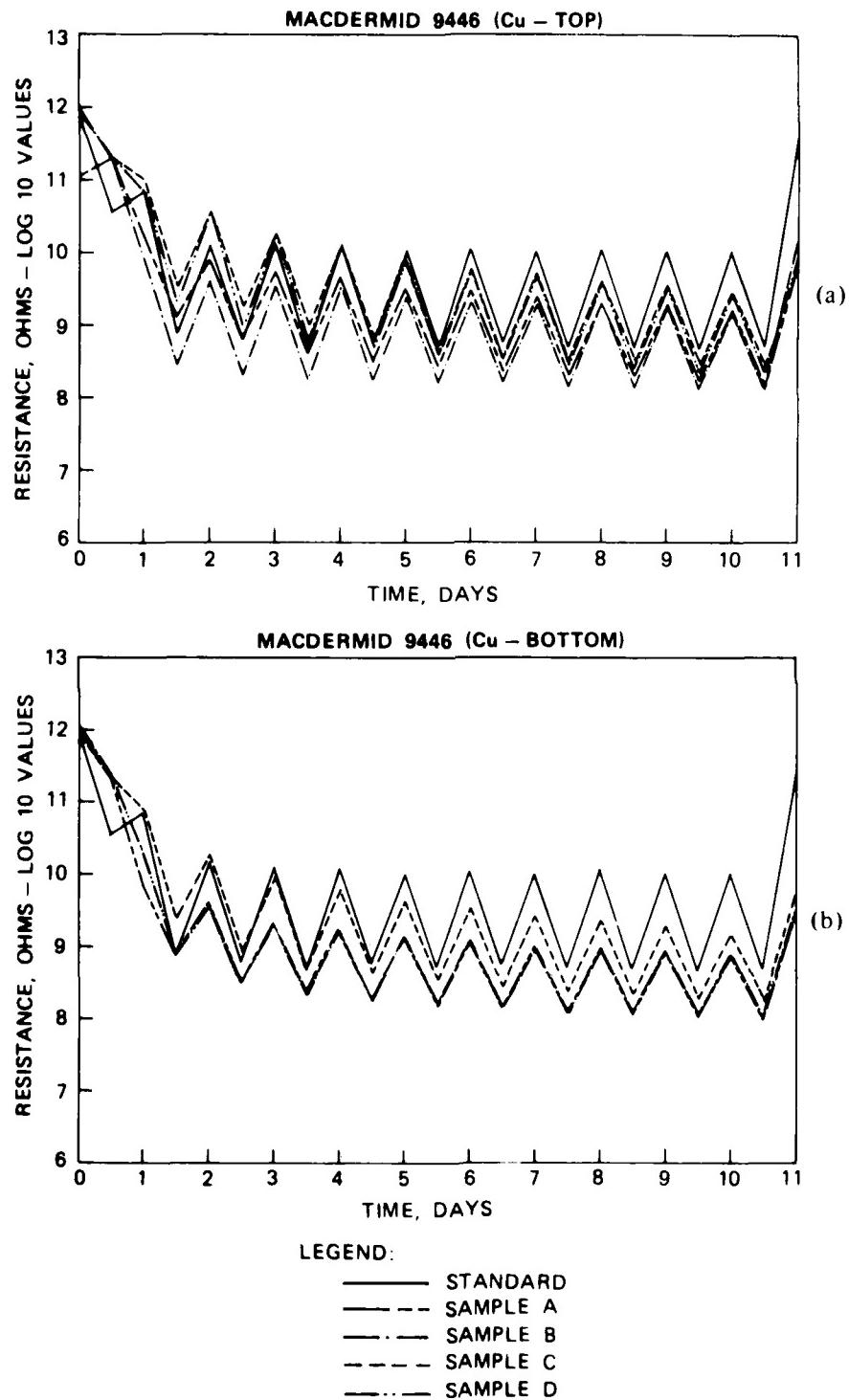


FIGURE 61. MacDermaid 9446, Resistance Readings, Copper.
(a) Top, (b) bottom.

NWC TP 6517

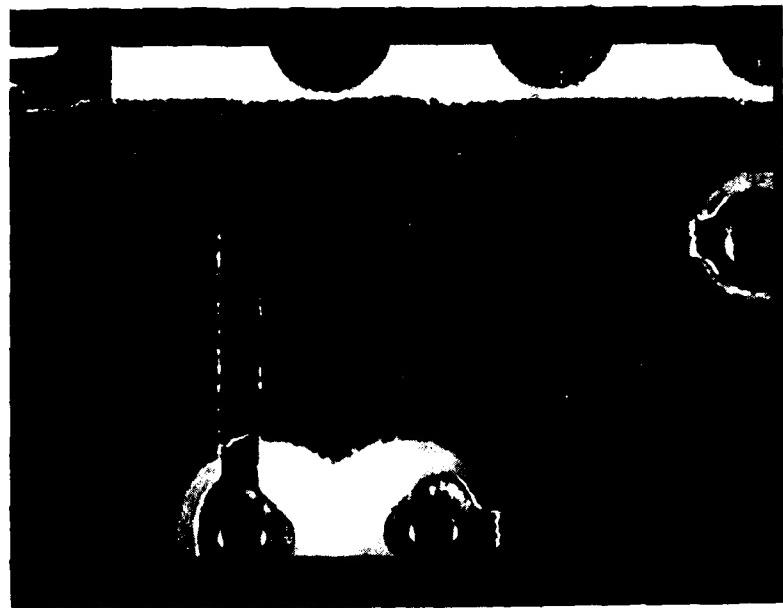


FIGURE 62. MacDermid 9446. Blisters on Traces Caused by Hot Air Leveling.

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CONCLUSION

The successful use of solder mask is greatly dependent on the quality of the mask application. Poor application procedures can change the expected properties of the mask, leading to later problems during the life of the masked board.

Surface preparation is extremely important; all oils, fibers, and other residues must be removed before a mask is applied or else the mask will not adhere properly.

Registration of the mask artwork is important to prevent masking of pad areas; solder mask on the surface of a pad can deform the fillet. The small pads that are coming into widespread use need their entire area to make a strong, defect-free connection. If part of these pads is covered by a misregistered solder mask or a mask that had bled, the strength of the joint is affected. Due to the bleeding effect of the liquid screenable solder masks, larger pad openings must be allowed to prevent misregistration. Dry film solder masks have closer registration tolerance since they do not bleed, thus making it possible for them to be used in areas with closely spaced pads.

Voids, bubbles, and pinholes adversely affect both the electrical and environmental protection that a solder mask can provide. Process controls practiced during masking can decrease the occurrence of these defects.

Since the liquid screenable solder masks cannot be consistently applied as pinhole-free coatings on a circuit board, they cannot be used as electrical insulating layers.

The thickness of a dry film mask aids its ability to protect against abrasion, dielectric breakdown, and environmental cycling, but it is important that the mask be properly applied and cured. Thiokol Dynachem Laminar RM should not be used due to the excessive blistering and loss of adhesion. The sensitivity of Laminar RM to isopropyl alcohol precludes its use in military electronics.

Solder mask cannot be used over a tin lead plating due to the wrinkling and flux entrapment that occurs during the wave soldering process. Entrapped residues can lead to degradation of the board at a later time.

Both the dry film and the liquid solder mask provide good protection against abrasion and adequately prevent soldering in the areas that are covered by mask. Some environmental cycling protection is also provided by both types of solder mask.

NWC TP 6517

To re-emphasize:

1. A liquid screenable solder mask shall not be used as an electrical insulating layer in Navy hardware.
2. Solder mask shall not be used over a tin/lead plating.

Appendix A

ABRASION TEST METHODS

TABER

An attachment hole was punched into the center of a circuit board, then the board was bolted onto the Taber Abrasion Tester turntable. A 1000-gram load was placed on the sample for a 50-cycle test. The amount of wear on the solder mask was then noted.

PENCIL

A 2H hardness pencil was pressed firmly onto the solder masked board in a down and forward motion then the mask was checked for damage. The pencil hardness was increased to 3H and then to 5H until the solder mask was scratched.

PUNCH

The solder masked board surface was firmly punched with a sharp pointed metal rod; any damage was noted.

Appendix B
ADHESION TEST METHODS

TAPE

A piece of Scotch 610 tape was firmly pressed onto the area to be tested. The tape was then rapidly pulled away at a 90-degree angle. The tape and board were inspected for mask that had been removed.

CROSS-HATCH

Five parallel cuts were made into the mask 1 16 inch apart using a razor blade, then five similar parallel cuts at right angles to the first cuts were made. Loose pieces of mask were brushed away then Scotch 610 tape was applied and removed as in the Tape Test Method. The tape and board were inspected for mask that had been removed.

Appendix C
SOLVENT RESISTANCE TEST METHOD

Small pieces of solder masked board containing both metal and laminate areas were soaked in eight different solvents for 2 hours. Periodic visual and mechanical checks were made to determine the effect of the solvent on the solder mask. The eight solvents were: isopropyl alcohol, acetone, methylene chloride, methyl ethyl ketone (MEK), tolene, xylene, cellosolve acetate, and dimethylsulfoxide (DMSO).

Appendix D

FLUX RESISTANCE TEST METHODS

IMMERSION

Small pieces of solder masked board containing both metal and laminate areas were soaked in flux for 2 days. Four different fluxes were used: one RMA, one RA, and two non-rosin fluxes. After 2 days, the samples were examined for degradation of the solder mask.

DROP

Two drops of the fluxes used in the immersion test were placed on small pieces of solder masked circuit board. After 2 days, the samples were examined for degradation of the solder mask.

Appendix E
MOISTURE TEMPERATURE CYCLING

Selected samples of solder masked boards were wave soldered, then moisture temperature cycled to determine the environmental properties of the masks.

Five boards with solder mask over tin/lead and four boards with mask over copper were prepared for wave soldering. The copper boards were cleaned in a mild alkaline detergent, rinsed with water, then dipped in ammonium persulfate $(\text{NH}_4)_2 \text{S}_2\text{O}_8$, water-rinsed again, then dipped in a 10% solution of sulfuric acid (H_2SO_4), then water-rinsed again before hot solder coating. Dried boards were brush-coated with Alpha 611F RMA flux then hand-dipped for 7 seconds in a 500 F Sn63 Pb37 solder pot followed by a "bump" and squeegee to clear the plated through holes. Boards were then vapor degreased in 1,1,1 trichloroethane.

Both the tin/lead and the copper boards were trimmed to size, cleaned, inspected for damage, and resistance-tested. Components were placed in one tin/lead and one copper board. Boards were spray fluxed with Alpha 611F RMA flux, then wave soldered on a Hollis TDL oil injection solder machine. A solder temperature of 500 F, an average top side laminate preheat temperature of 180°F, medium oil on the wave, and a 2-second dwell in the wave were the conditions of soldering.

A vapor degreasing in Freon TB for 2 minutes immersed in the boiling tank, 1 minute immersed in the warm tank, and 1 minute suspended in the vapors was used to clean the boards after wave soldering.

Cleanliness tests were performed on three of the wave soldered boards to assure that the cleaning process was in order. An Alpha Metals Ionograph with a solution of 75% isopropyl alcohol/25% deionized water was used to test for ionic cleanliness. Conditions of test were: 0.02 micromho/centimeter starting conductivity, pump rate 8 1/2, and 40 counts/second. Less than 10 micrograms square inch was considered a passing value for ionic cleanliness.

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All wave soldered boards were handled with clean cotton gloves for inspection at 20X before starting the 10-day moisture/temperature cycling test. The cycling test was a modified version of MIL-STD-202 Method 106E. See Figure E-1. Four tin/lead boards and four copper boards that had been wave soldered and one standard unmasked tin/lead board that had not been wave soldered were placed into an insulation resistance test set inside a Blue M Model FR-256PC-1 environmental chamber.

The insulation resistance test set consisted of 10 gold-tipped edge connectors that mated to the finger tabs on the test boards. The connectors were wired into an open-sided frame that allowed for unrestricted air flow inside the chamber. Wiring through a port in the chamber connected the insulation resistance set to a selector box, then to a GenRad Model 1644A megohm bridge. See Figure E-2. The selector box was used to choose which of the 10 connectors was to be tested. The megohm bridge supplied 100 VDC across the 0.006-inch comb pattern for a 1-minute period before the resistance value was recorded. Readings were taken two times each day, once at the low temperature phase of the cycle and once at the high temperature phase of the cycle. Measurements were made on both the top and bottom sides of the boards. At the end of the 10-day period, the chamber was opened and allowed to cool for 2 hours before a final resistance was recorded. A failure was classified as a sample having resistance values lower than the standard unmasked board and in the megohm range.

Resistance values of an open connector were recorded during each test to ensure that the system was operating correctly.

All boards were then inspected at 20X following the test.

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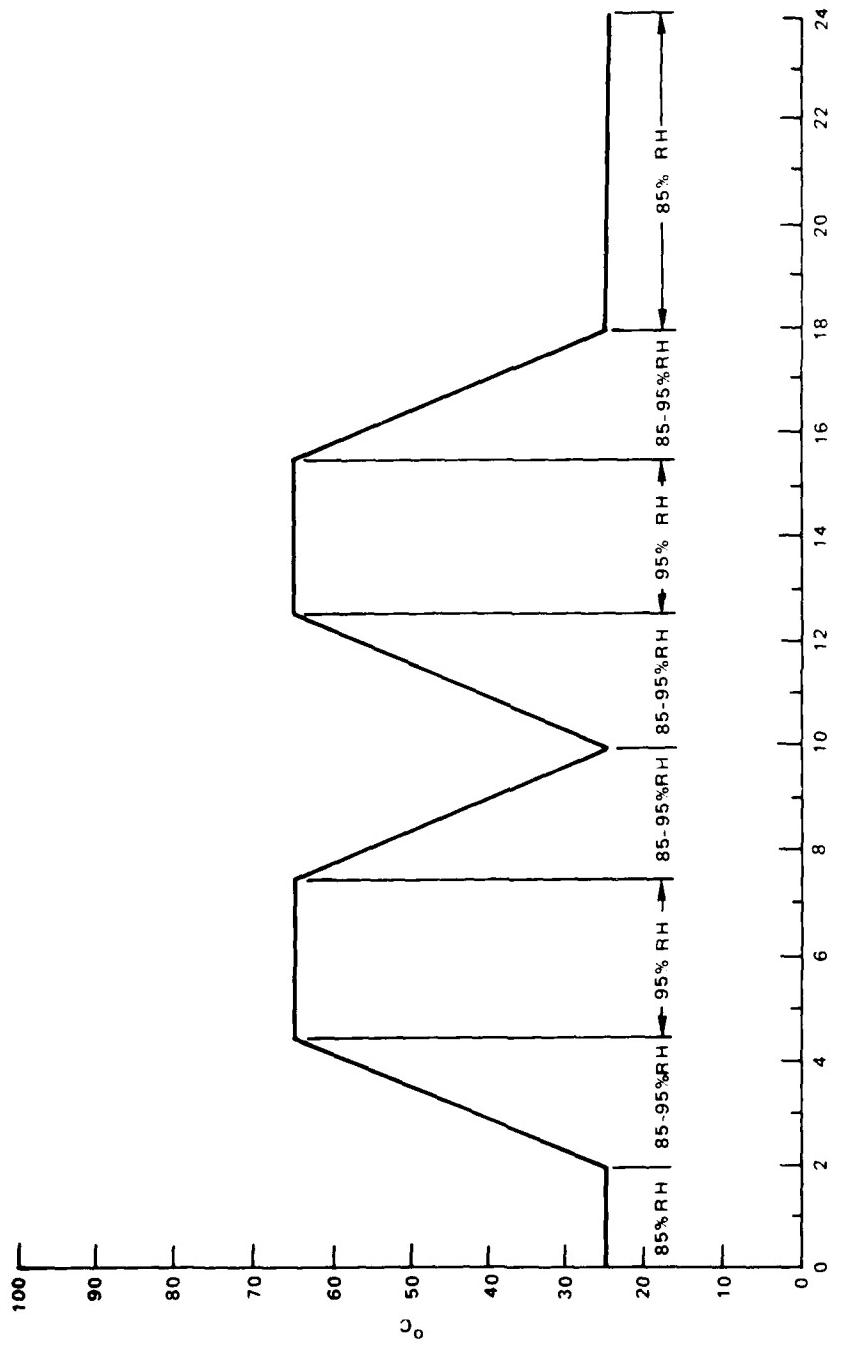


FIGURE E-1. Modified Version, MIL-STD-202, Method 106I.

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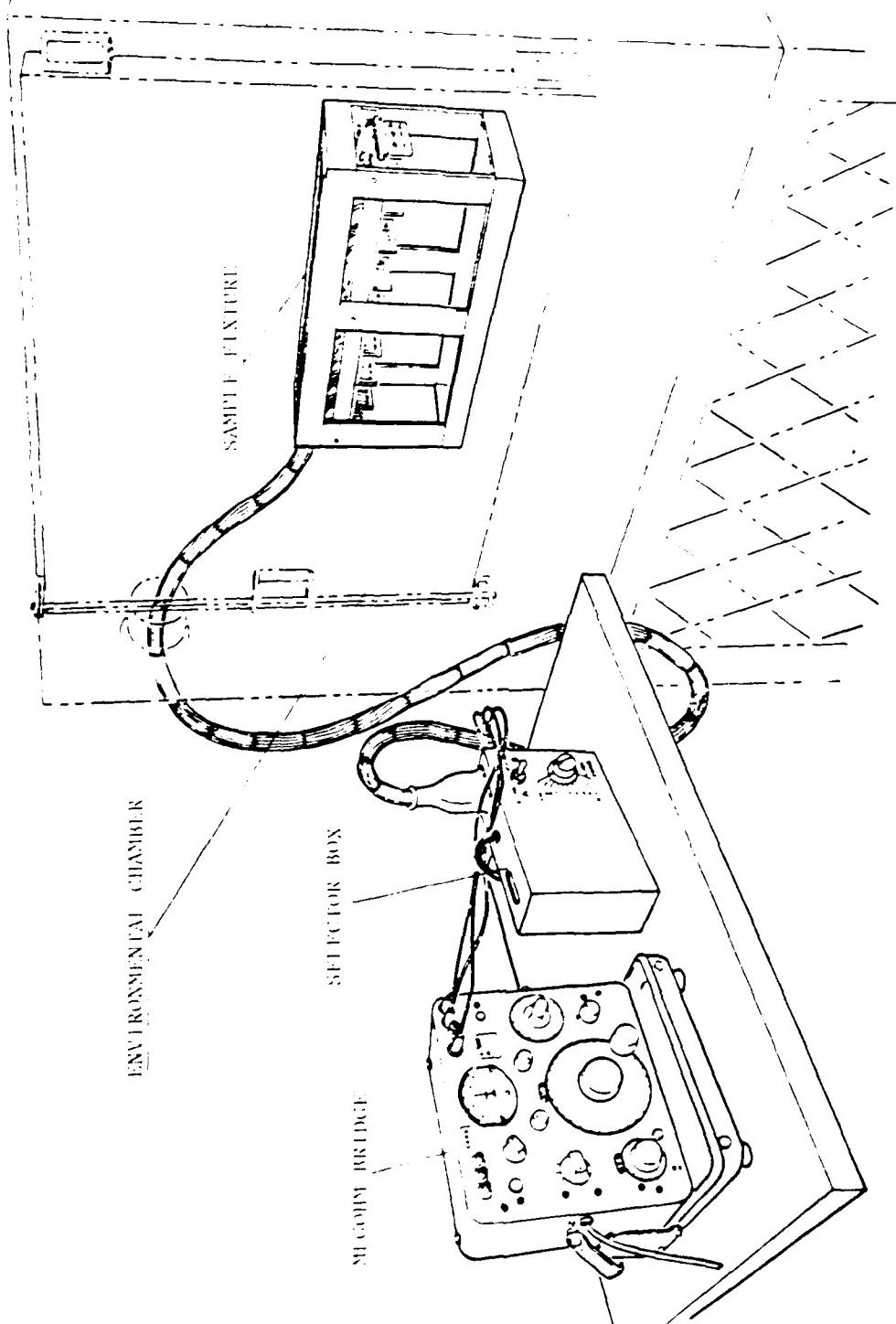


FIGURE E-2. Connector System.

Appendix F

ELECTRICAL TEST METHODS

BREAKDOWN VOLTAGE

The breakdown voltage of the solder mask over the ground plane was tested using a Hypotronics Model H306B high-voltage power supply. A wire was soldered to the unmasked area of the tin/lead ground plane and a 0.25-inch-diameter polished brass electrode was placed on the solder masked area of the ground plane. A 75-gram weight was placed on top of the electrode to ensure good surface contact. See Figure F-1. Voltage was applied in 1000-V increments for 1-minute periods until a breakdown occurred. A breakdown was classified as a current of 50 microamps or greater passing through the solder mask. DC voltage was used first from 0-6000 V and if no failure occurred, AC voltage was used.

SURFACE RESISTIVITY

The surface resistivity of the solder mask was tested using a GenRad Model 1644A megohm bridge. Two polished brass electrodes 1 x 0.5 inch were placed 1 inch apart on the open area of solder masked laminate. A 75-gram weight was placed on top of the electrodes to ensure good surface contact and to keep the 1-inch spacing. See Figure F-2. A voltage of 500 VDC was applied to the electrodes for 1 minute, after which time a resistance measurement was recorded.

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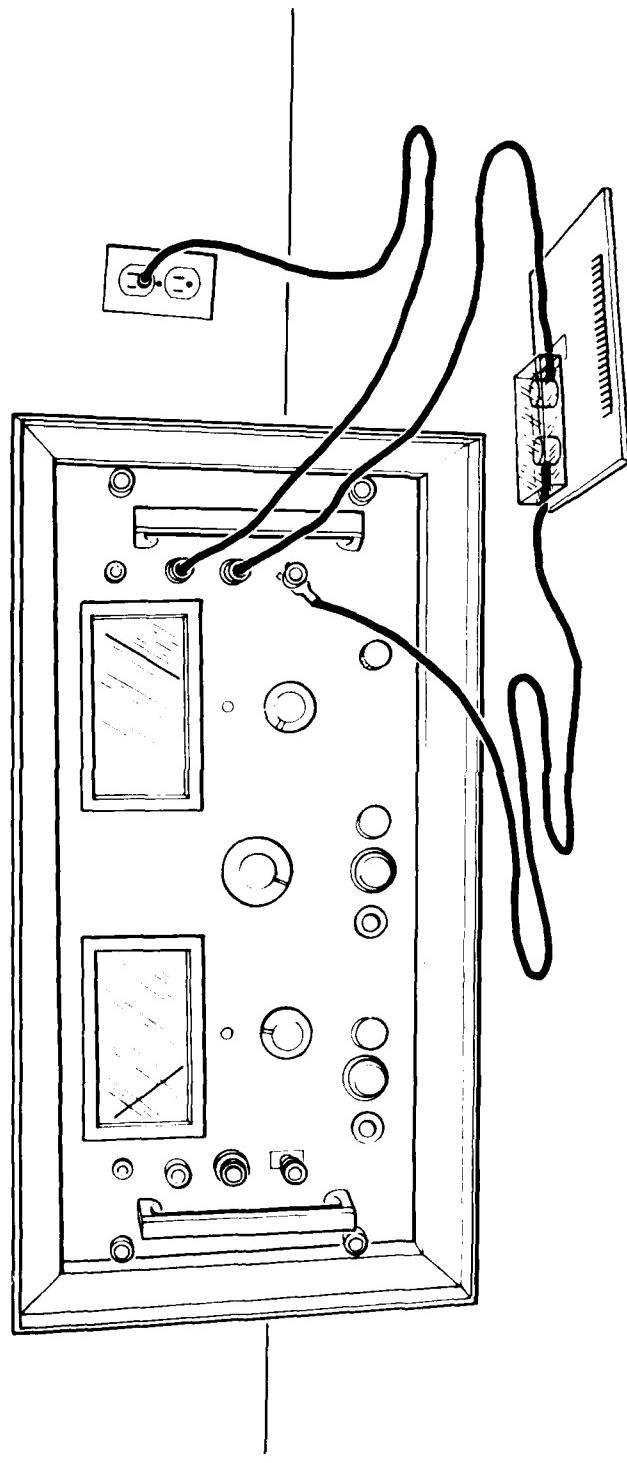


FIGURE F-1. Breakdown Voltage Test Set.

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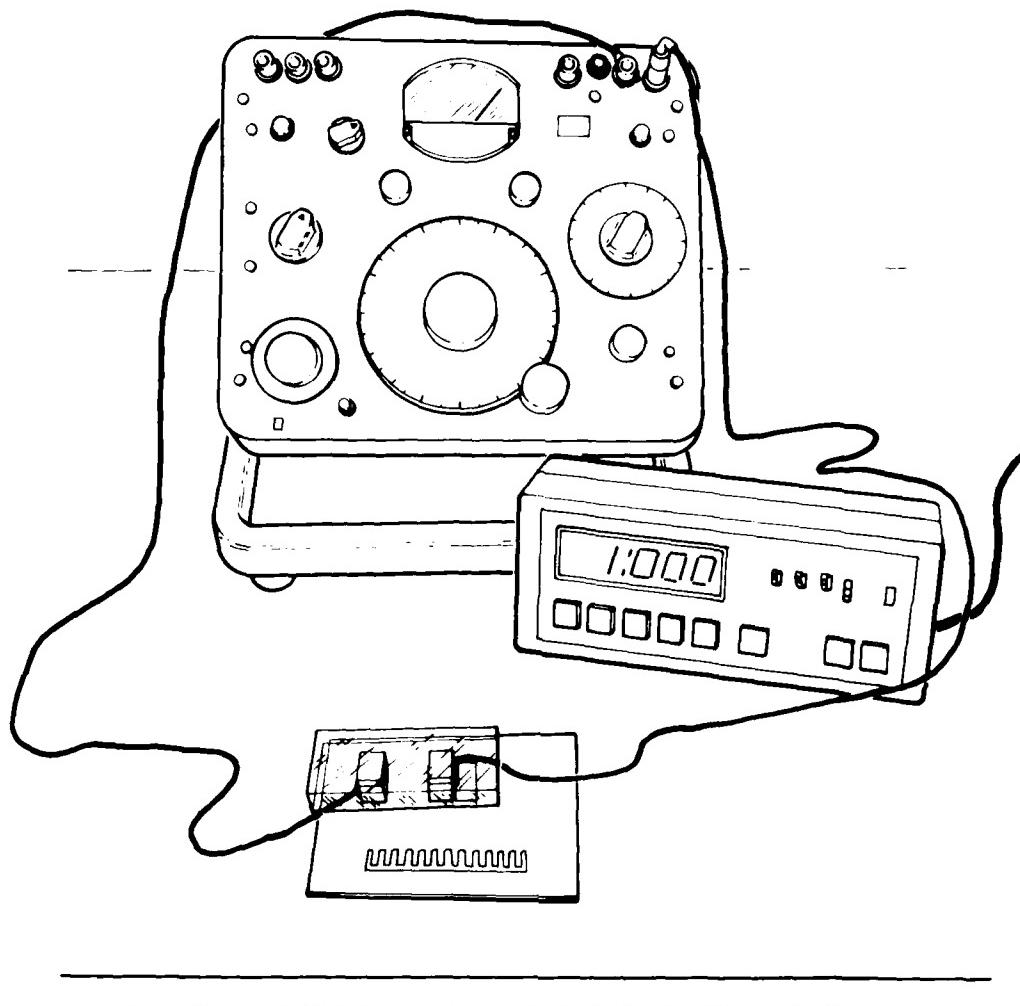


FIGURE F-2. Surface Resistivity Test Set.

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